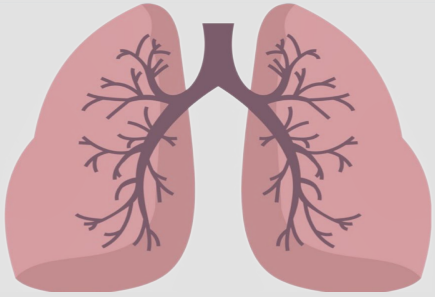
Oxygen & Carbon dioxide transport



Respiratory Block

Physiology 439 team work

- Black: in male / female slides
- Red : important
- Pink: in female slides only
- Blue: in male slides only
- Green: notes
- Gray: extra information
- Textbook: Guyton + Linda

Editing file

@Physiology_439

Objectives :

01 Differentiate between O_2 capacity, O_2 content and O_2 saturation.

02 Describe Oxygen- hemoglobin dissociation curve.

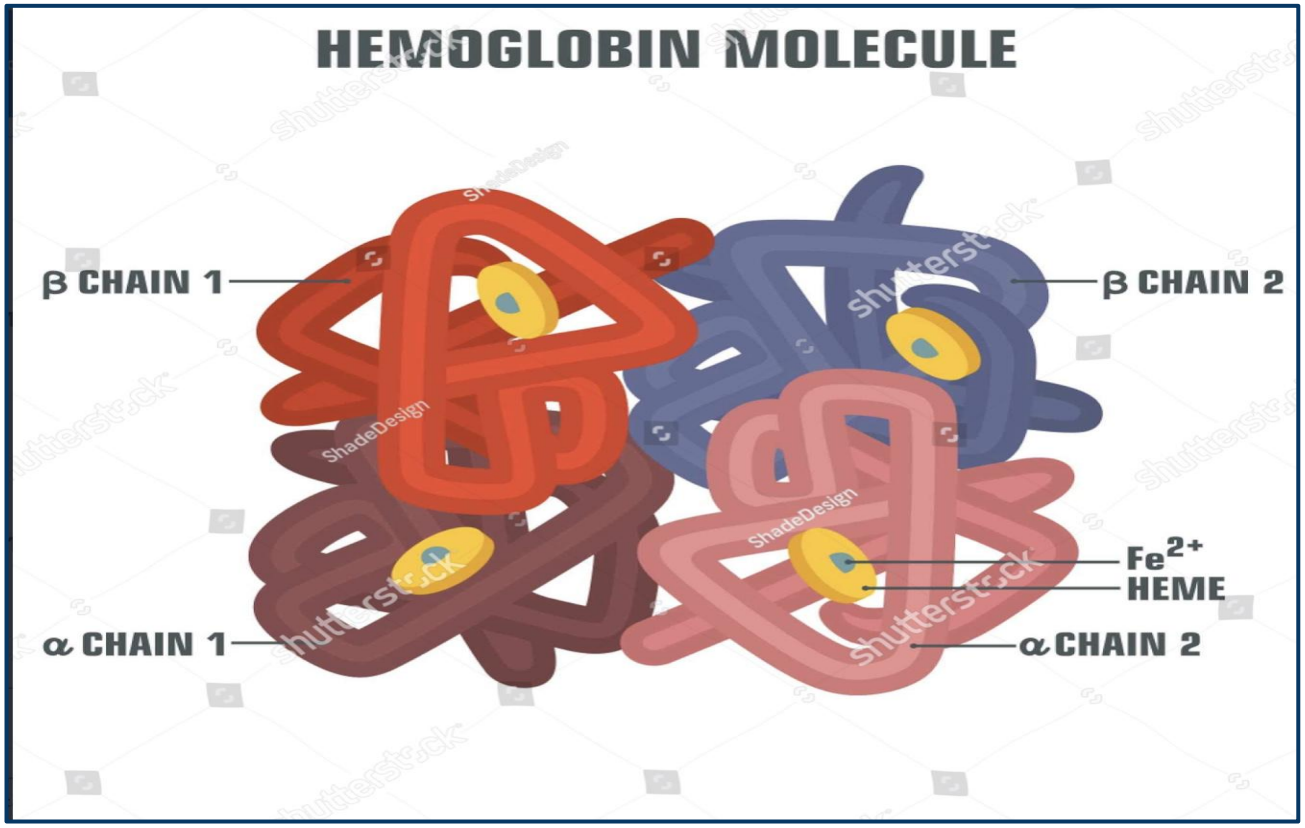
03 How DPG, temperature, H+ ions and PCO2 affect affinity of O2 for Hemoglobin and the physiological importance of these effects.

04 Define the P50 and its significance.

05 Understand the forms of oxygen transport in the blood, the importance of each.

06 Describe the three forms of carbon dioxide that are transported in the blood, and the chloride shift.

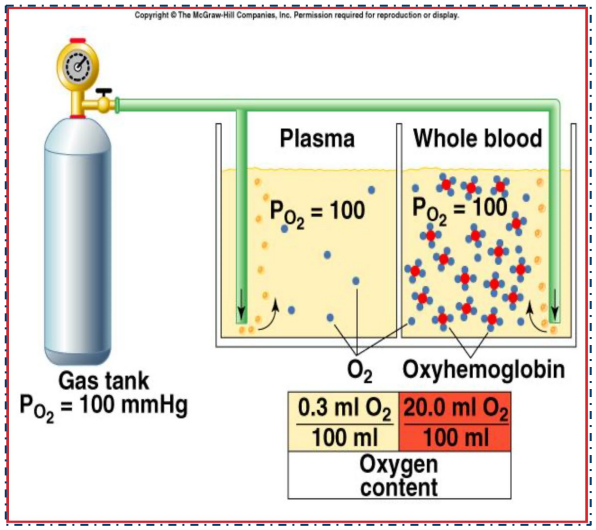
First before we begin let's fresh our information about hemoglobin



Hemoglobin is the iron-containing protein found in all red blood cells (RBCs) that gives the cells their characteristic red color. Hemoglobin enables RBCs to bind to oxygen in the lungs and carry it to tissues and organs throughout the body.

Forms of O_2 transport

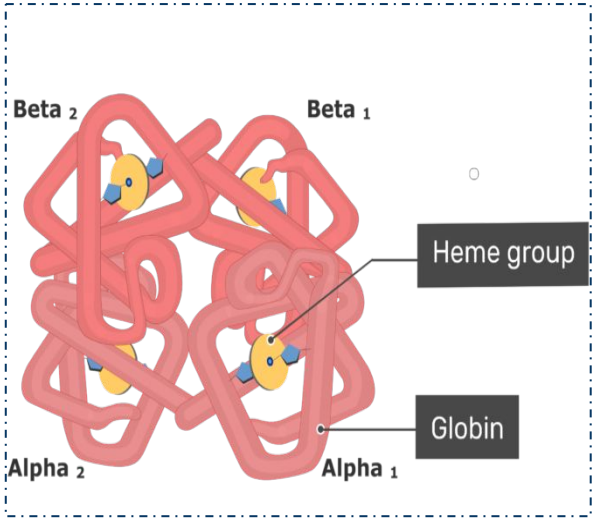
The presence of hemoglobin in the red blood cells allows the blood to transport 30 to 100 times as much oxygen as could be transported in the form of dissolved oxygen in the water of the blood.



Transport of O2 and CO2 in blood and body fluids

O2 is mostly transported in the blood bound to hemoglobin more than in dissolved state.

- If the PO2 increases Hb binds O2.
- If PO2 decreases Hb releases O2.
- O2 binds to the heme group on hemoglobin, with 4 oxygens /Hb. (8 atoms)



كل ما زاد الـ(PO2) زاد ارتباط الـ(Hemoglobin) مع الـ(Oxygen).

Terminology:

- **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.
- **Percent saturation**: percentage of heme groups bound to O_2

$$\%\text{saturation } \textit{of Hb} = \frac{\textbf{Oxygen content}}{\textbf{O}_2\textbf{-binding capacity}} \times 100$$

- **Dissolved O_2**: Unbound O_2 in blood (ml O_2/100 ml blood).

Transport of oxygen in arterial blood

- **When blood is 100% saturated:**
- each gram of Hb carries 1.34 ml O2.
- O2-binding capacity = 15g Hb x 1.34 O2=20.1 ml.

احنا نعرف ان الهيموجلوبين يختلف بين الإناث والذكور لكن ال15 هو متوسط الهيموجلوبين في أجسامنا

But

If the blood is only 97% saturated:

-each 100 ml blood contain 19.4 ml O2.

- Amount of oxygen released from hemoglobin to the tissues is: 5ml/100ml blood. * we used this 5ml of O2 during resting condition*
- O2-binding capacity in venous blood =19.4 -5= 14.4 ml.

O2 binding capacity is the same as O2 content

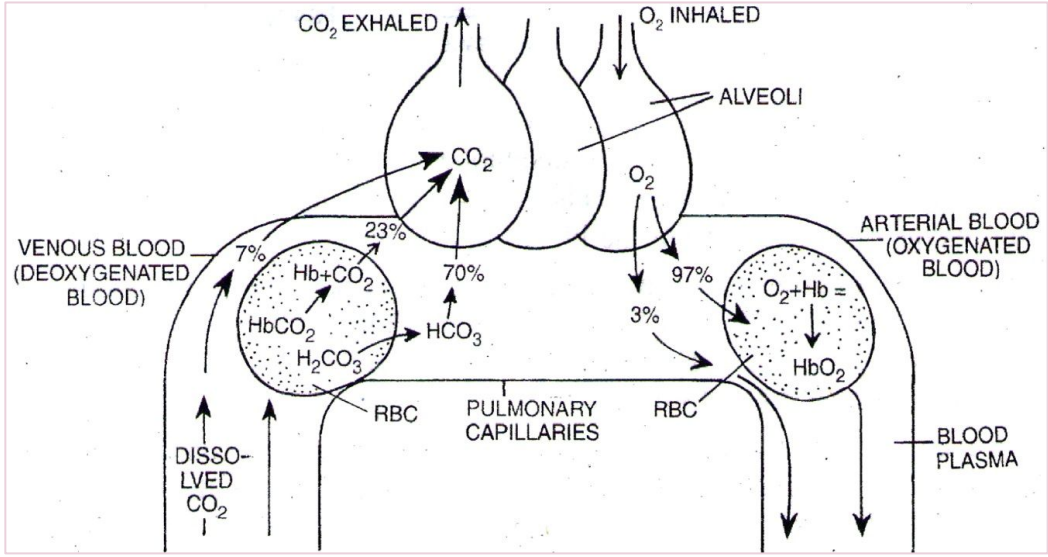
- **During strenuous exercise:** oxygen -uptake by the tissue increases 3-5 folds.

15 ml O2 is given to the tissues /100 ml blood.

- **O2 binding capacity in venous blood** =19.4-15=4.4 ml O2 /100 ml blood.

- At rest, tissues consume **250 ml O2 /min** and produce **200ml CO2.**

الطبيعي في أجسامنا نوصل تشبع بمقدار 97% مانوصل 100%



Important

Oxygen transport in blood

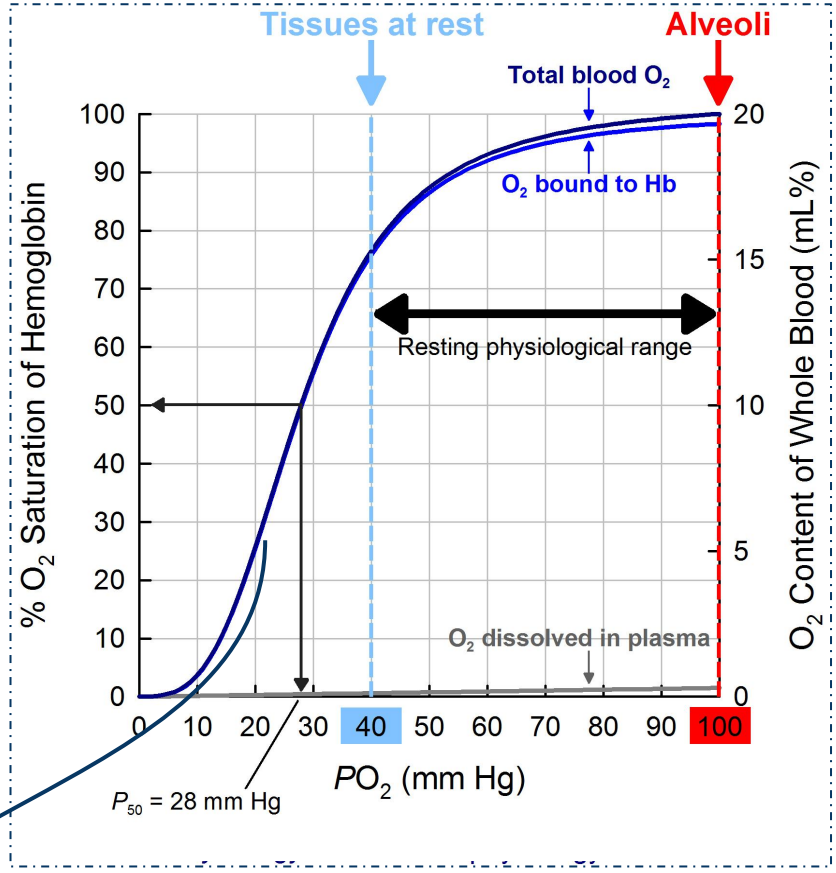
01 3% dissolved in plasma.

02 97% bound to hemoglobin (oxyhemoglobin).

*Higher PO2 results in greater Hb saturation.
*The relation between PO2 and Hb-O2 is not linear.

The curve is called:

Oxygen hemoglobin Saturation Curve Which is **S- shaped or sigmoidal.**



The graph is Sigmoid in shape because:
1- The first oxygen binding is slower than the others, when it binds is make the others bind faster **(Cooperativity).**
2- at the end of the curve most of the hemoglobin molecules becomes saturated with oxygen.

Factors that shift O2-Hb dissociation curve to the right

- ***Temperature***
- ***2,3-DPGb*** *(END PRODUCT OF GLYCOLYSIS)*
- ***Pco2 (Bohr effect)*** ** the explanation will be in next slides*
- ***P50(lower affinity for O2)***

- **PH (high H+ conc)**

The position of the dissociation curve can be determined by measuring the **P50**

Decreased P50 means: increased affinity of Hb to O2 or shift of the curve to left

Increased P50 means: decreased affinity or shift of the curve to right.

P50: The arterial PO2 at which 50% of Hb is saturated with O2, normally P50=26.5

Fetal Hb: has a P50 of 20 mmHg in comparison to 27 mmHg of adult Hb.

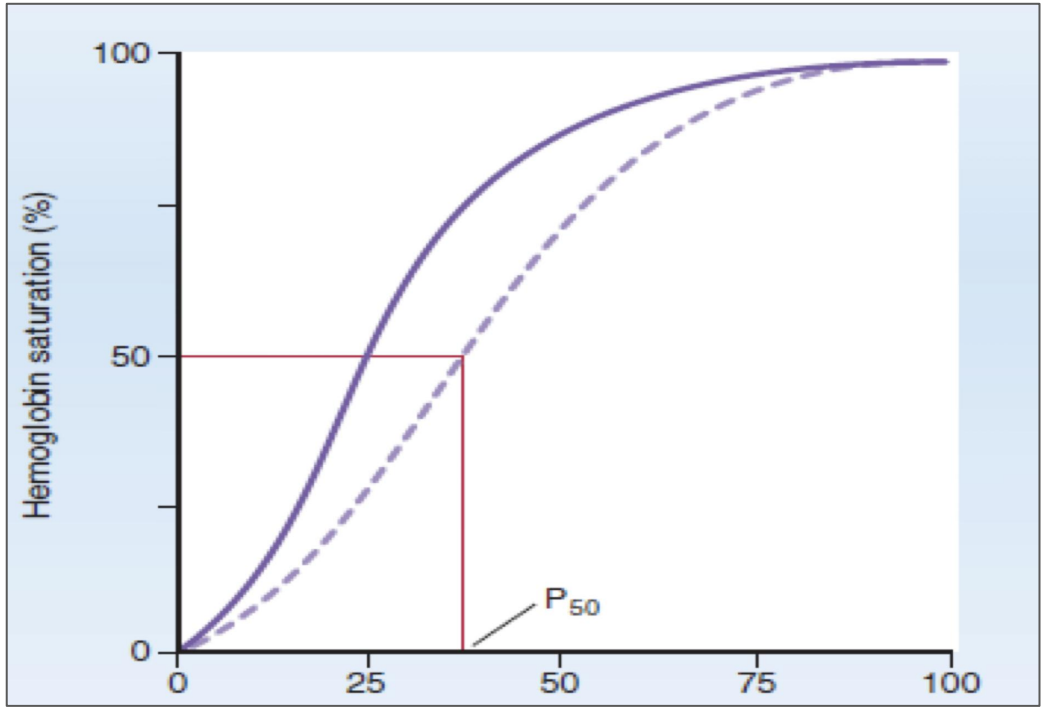
إذا كان الضغط أكبر من 27 (RIGHT SHIFT) , وإذا كان الضغط أقل من 27 (LEFT SHIFT)

2,3-DPG Enzyme inside the cell decrease the affinity between the O2 and heme so when it is found in high level it will shift to the right and when it is found in low level will increase the affinity.

Low affinity كويس في الtissue عشان يوفر لها أكسجين بسهوله بس مو زينه في الLung

If I do exercise the temperature and Pco2 will increase so it shift to the right

the oxygen is unloaded to the tissues from Hb
(hemoglobin affinity for oxygen is decreased)



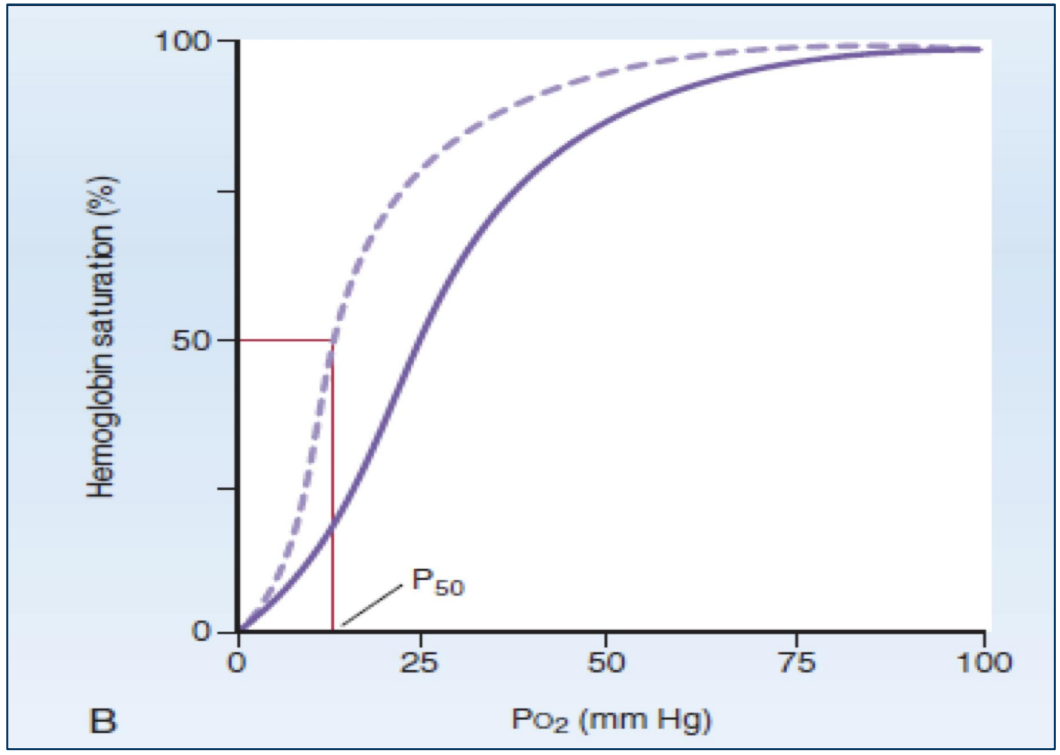
Factors that shift O2-Hb dissociation curve to the left

- ***Temperature***
- ***2,3-DPGb*** *(END PRODUCT OF GLYCOLYSIS)*
- ***Pco2 (Bohr effect)*** **the explanation will be in next slides*
- ***P50(higher affinity for O2)***

- **Ph (low H+ conc)**
- Fetal haemoglobin

loading or attachment of oxygen to Hb.
(hemoglobin affinity for oxygen is increased)

High affinity is GOOD for LUNG **BUT** Bad for TISSUE Why ??
عشان لما يوصل للخلايا وهو ماسك الأكسجين بقوه ماراح يقدر يفك بالتالي ماراح يوفره لهم



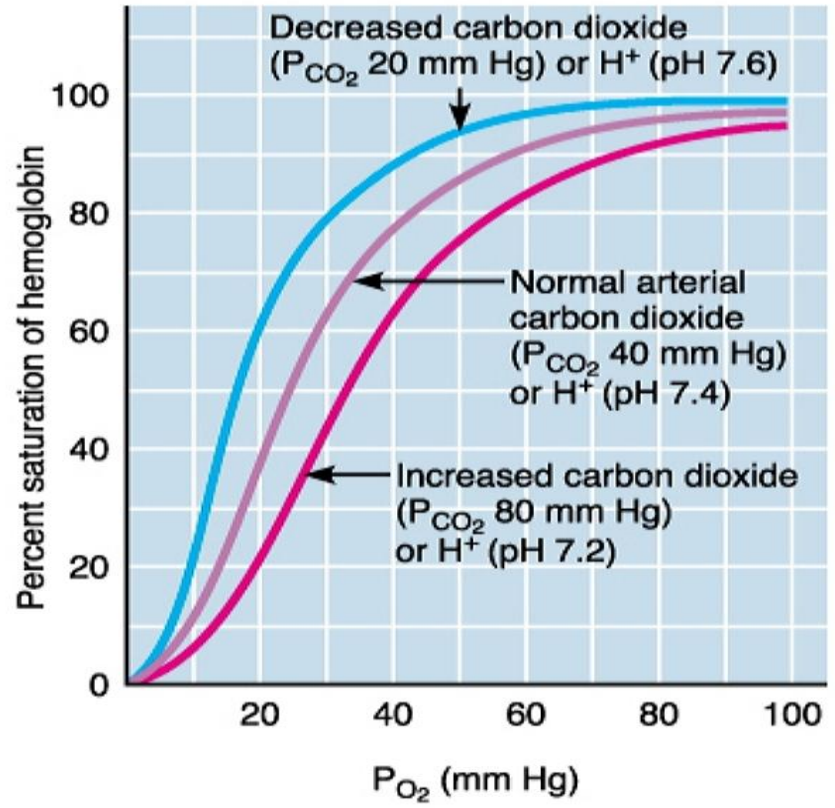
Bohr's effect:

Effect of carbon dioxide and hydrogen ions on the curve

- **At lung**: movement of CO2 from blood to alveoli will decrease blood CO2&H+ →shift the curve to left and increase O2 affinity to Hb allowing more O2 transport to tissues.
- **At tissues**: the reverse occurs.

More explanation

From Linda:
Bohr effect, which can be explained as follows: As the blood passes through the tissues, carbon dioxide diffuses from the tissue cells into the blood.This increases the blood PO2, which in turn raises the blood H2CO3 (carbonic acid) and the hydrogen ion concentration. These effects shift the oxygen-hemoglobin dissociation curve to the right and downward,, forcing oxygen away from the hemoglobin and therefore delivering increased amounts of oxygen to the tissues. Exactly the opposite effects occur in the lungs, where carbon dioxide diffuses from the blood into the alveoli. This reduces the blood PCO2 and decreases the hydrogen ion concentration, shifting the oxygen-hemoglobin dissociation curve to the left and upward. Therefore, the quantity of oxygen that binds with the hemoglobin at any given alveolar PO2 becomes considerably increased, thus allowing greater oxygen transport to the tissues.



Explanation

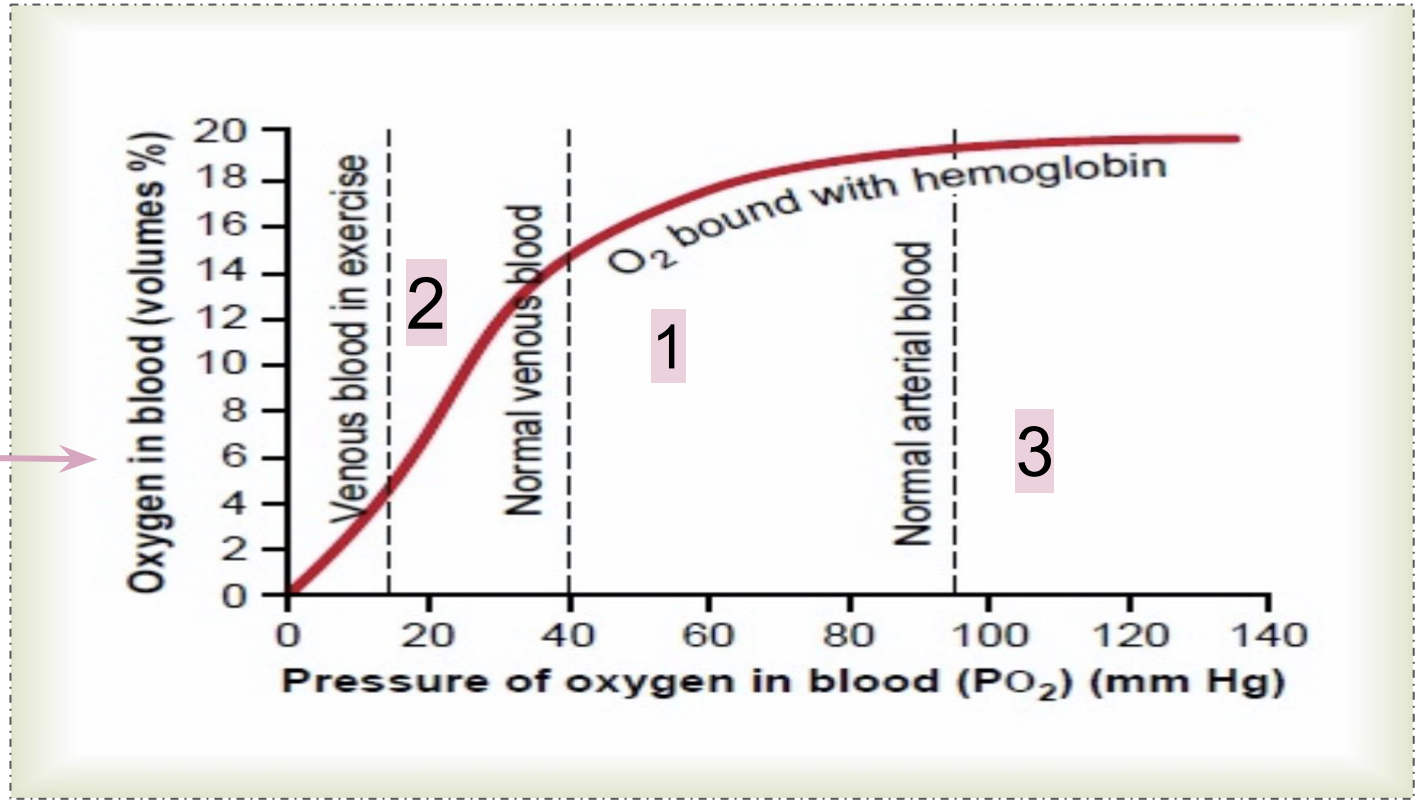
Oxyhemoglobin Dissociation curve

كميه الأكسجين اللي ماسكه ب الهيموجلوبين و حسبناها فوق

100% saturation of hemoglobin—-20 of O2 /dl

97% saturation of hemoglobin in arterial blood =20*97%=19.4 ml of o2/dl

75% saturation of hemoglobin in the venous blood = 20*75%=15 ml of o2 dl



1

venous blood اللي Po2 فيه تساوي 40 بشكل طبيعي وأثناء ما احنا مرتاحين وما نسوي أي شغل وجهد استخدمنا بس 5ml من الأكسجين و تبقت كمية الأكسجين اللي ماسكه بالهيموجلوبين 15ml متى نستخدمه طيب؟ هو كأنه أكسجين احتياطي عشان لو بذلنا مجهود نستخدمه

2

اثناء الجهد بنحتاج أكسجين اكثر ف راح نستخدم هذي ال15
ونستهلك منها ف راح يقل تقريبًا 4.4
ويقل معها Venous Po2 إلى
20 mmHg

3

جالس يوضح لنا كميه الأكسجين في ال arterial blood االلي Po2 فيه تساوي 100 يساوي 19.4

2,3-diphosphoglycerate (2,3-DPG)

01 **in RBCs from the glycolytic pathway**

02 **It binds tightly to reduced Hb**

If increased, it facilitate the oxygen release and shifts the dissociation curve to the right.

03 **increases in the RBCs in anemia and hypoxemia**

serves as an important adaptive response in maintaining tissue oxygenation

Hemoglobin in adults is consist of 2a+2B. Unlike in children, it consists of 2a + 2λ.
2,3DPG Binds to Beta chain of Hb & cross link this chain making Hb pocket smaller which leads to the release of O2.
DPG merges the 2 chains of Beta which decrease the area of hemoglobin. So, O_2 needs to get out.

Because children do not have beta chain, The effect of DPG is less on them and this explain that:
More PO_2 → More Hemoglobin Saturation → More Affinity → Less O_2 release → Left shift

Pulse oximetry

Measures % saturation of arterial blood (e.g., of the finger) using dual-wavelength spectrophotometry.
Because oxyhemoglobin and deoxyhemoglobin have different absorbance characteristics,
the machine calculates :% saturation from absorbance at two different wavelengths.

Pulse oximetry measures: arterial % saturation because arterial blood "pulses" whereas venous and capillary Blood do not; background absorbance from venous and capillary blood is subtracted out.

Pulse oximetry does not directly measure PaO2. However, knowing % saturation, one can estimate PaO2 from the O2-hemoglobin dissociation curve.

Only in girls slide

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 is called utilization coefficient.

$$\text{Utilization Coefficient} = \frac{O_2 \text{ delivered to the tissues}}{O_2 \text{ content of arterial blood}}$$

Normally at rest : 5 ml/20 ml= 25% ,

During exercise; 15 ml/20 ml = 75 % - 85%

Transport of oxygen in dissolved state

- Only **3%** of O2 is transported in the dissolved state.
- At normal arterial PO2 of 95 mmHg , about 0.29 ml of oxygen is
  dissolved in each 100ml of blood.
- When the PO2 of the blood falls to 40 mmHg in tissue capillaries, only 0.12 of oxygen remains dissolved.
- Therefore 0.17 ml of oxygen is normally transported in the
  dissolved state to the tissues per each 100 ml of blood.

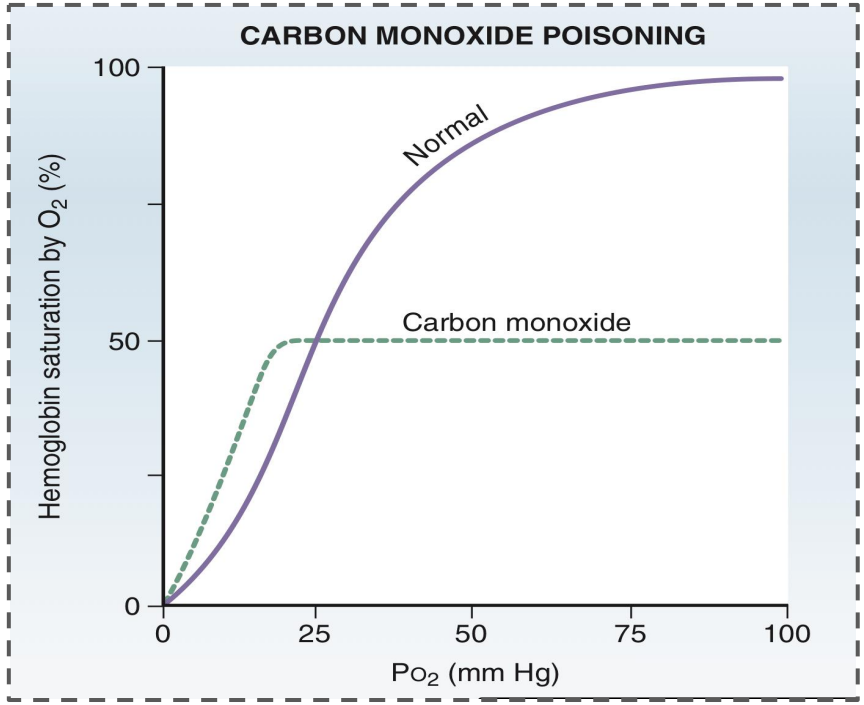
القرنية (cornea) و cartilages لا يصلها الدم اي لا تصلها كريات الدم الحمراء فيغذيها البلازما، فتتغذا بالاوكسجين الذائب ليس بالهيموجلوبين

بسبب ان نسب الاوكسيجين الذائبة في البلازما قليلة جدا يلجأ الجسم لاستخدام الهيموجلوبين لنقل الاوكسجين

Combination of Hb with CO (displacement of oxygen)

- 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 O2 (affinity of Hb to CO is very high (250 times) that to O2.
- It causes lift shift of the O2-Hb curve.

From Linda:
these two effects of CO on O2 binding to hemoglobin are catastrophic for O2 delivery to tissues. Not only is there reduced O2-binding capacity of hemoglobin, but the remaining heme sites bind O2 more tightly



Transport of carbon dioxide in the blood

Carbon dioxide is transported in three forms :

7%

Dissolved CO2

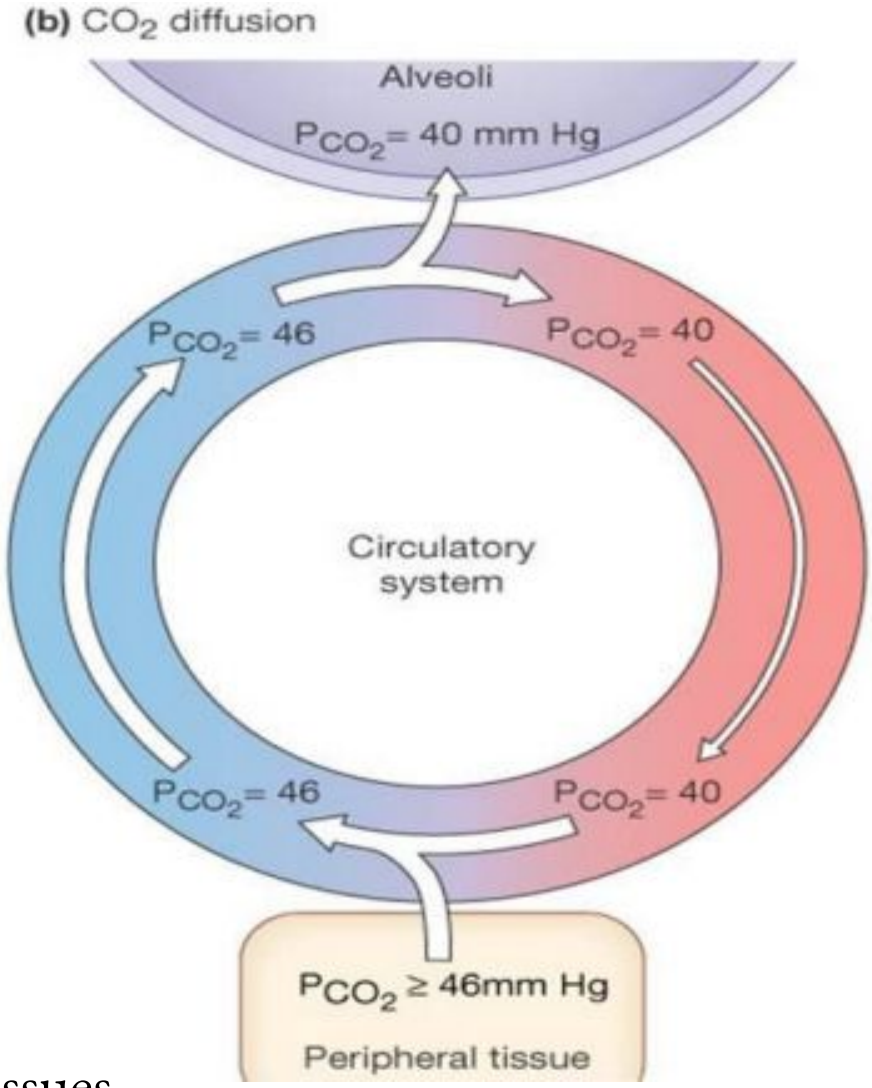
23%

Carbaminohemoglobin (with Hb)

01 **02** **03**

70%

Bicarbonate ions

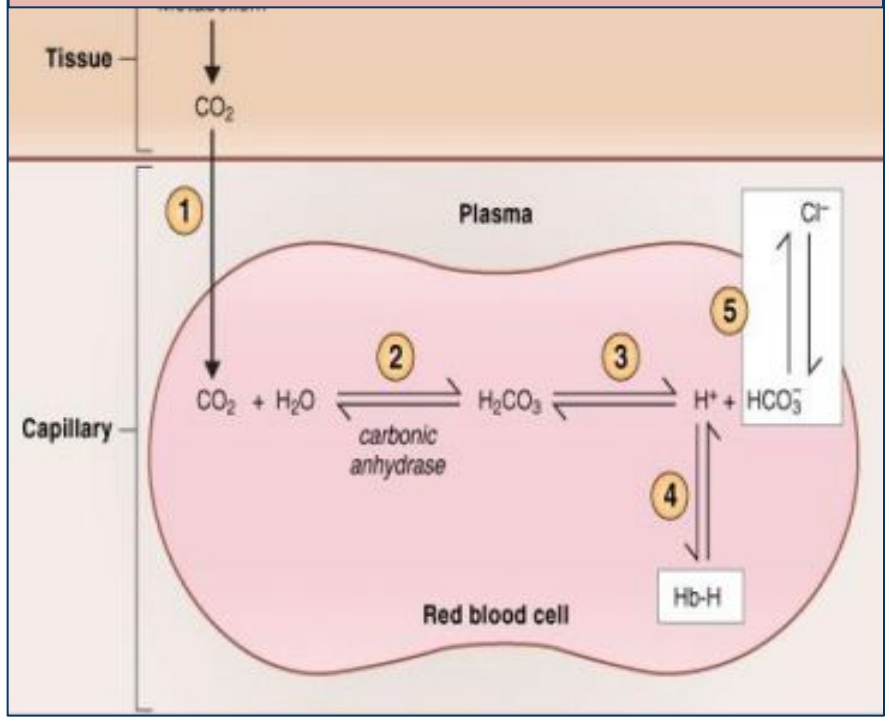


- Each 100 ml of blood carry 4 ml of CO2 from the tissues

Remember that:Transport of CO2 from the tissues to the lungs in venous blood.

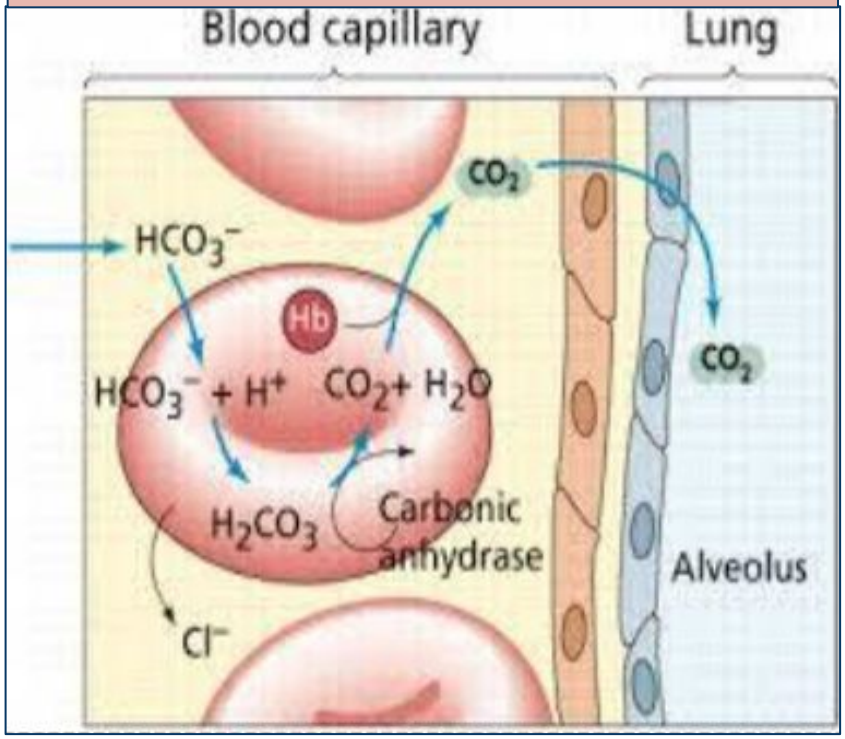
Formation of HCO3- and Chloride shift

In Tissues



- الCO2 يتحد مع الماء (very slow reaction but RBC have carbonic Anhydrase enzyme to increase it) ويكون H2CO3 بعدها يتحلل الى (HCO3- + H). ال HCO3- يخرج الى البلازما عن طريق دخول كلور. اما H فيرتبط مع Hb ونستفيد منه بالحفاظ على PH (درجة الحموضة والقاعدية) إذا زاد الPH نفصل الH من الHb "
الهيدروجين يرتبط في الهيموجلوبين في الamino acid chain"

In Pulmonary capillaries



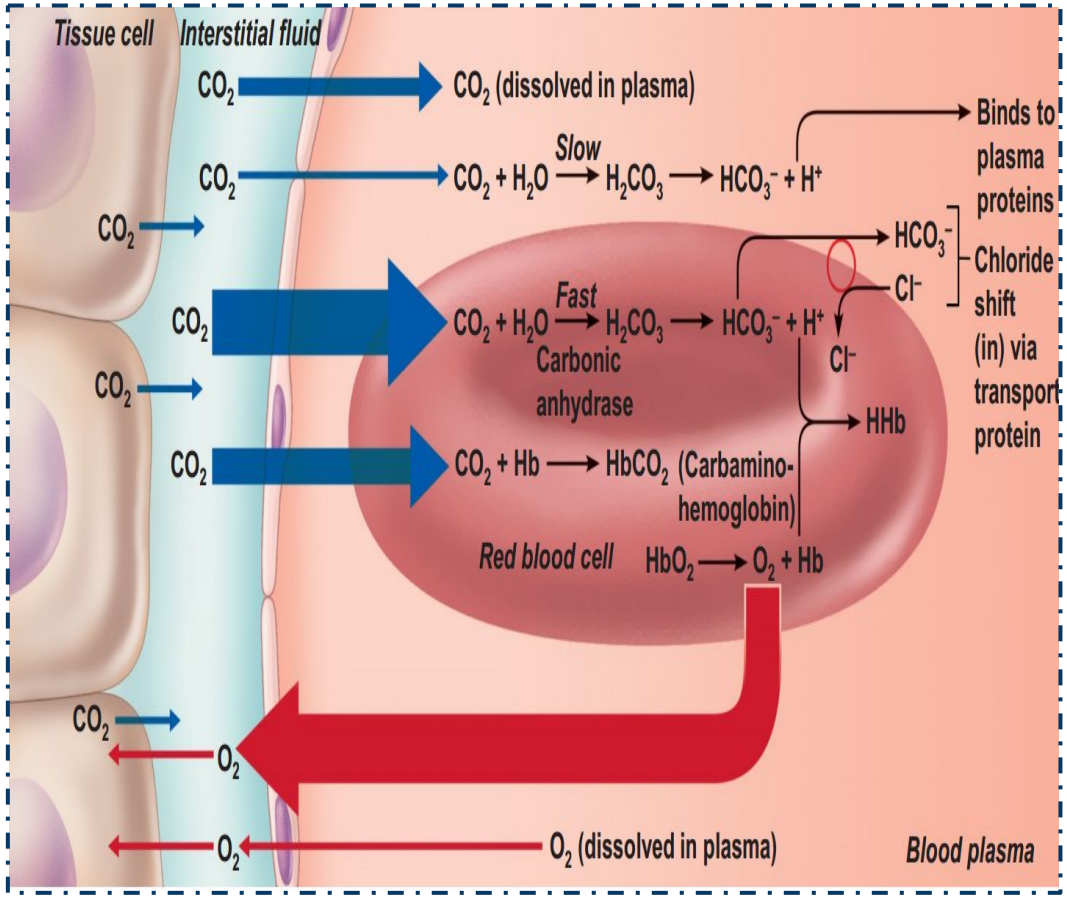
هي عملية عكس العمليه الي في النسيج، يرتبط ال HCO3- مع هيدروجين وينتج (ماء +CO2) ينتقل الCO2 الى الalveolus ليخرج خارج الجسم (Expiration)

نلاحظ ان الhemoglobin يعمل ك buffer للحفاظ على الpH

طبعًا احنا عندنا قاعدة تقول أن إذا دخل أيون للخلية لازم يطلع أيون مساوي له بالمقدار وهذا يفسر حركة الكلور والBicarbonate أحدهم عكس اتجاه الآخر

The haldane effect

- When oxygen binds with hemoglobin , carbon dioxide is released- to increase CO2 transport (in the gas exchange area).
- Binding of Hb with O2 at the lung causes the Hb to become a stronger acid (increase H^+) , this in turn displaces CO2 from the blood and into the alveoli (expiration)
- Change in blood acidity during CO2 transport.
- Arterial blood has a PH of 7.41 that of venous blood with higher PCO2 falls to 7.37
  (i.e change of 0.04 unit takes place)



Respiratory exchange ratio
(Respiratory Quotient)

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

- Normally it is 4/5= 82%
- A person on normal diet: R=0.825
- When Carbohydrate diet is used: R = 1
- When fats only is used: R=0.7
- The reason for this difference is that when O2 is metabolized with carbohydrates, one molecule of CO2 is formed for each molecule of O2 consumed; when O2 reacts with fats, a large share of the O2 combines with hydrogen atoms from the fats to form water instead of CO2.

Summary

The presence of hemoglobin in the red blood cells allows the blood to transport 30 to 100 times as much oxygen as could be transported in the form of dissolved oxygen in the water of the blood.

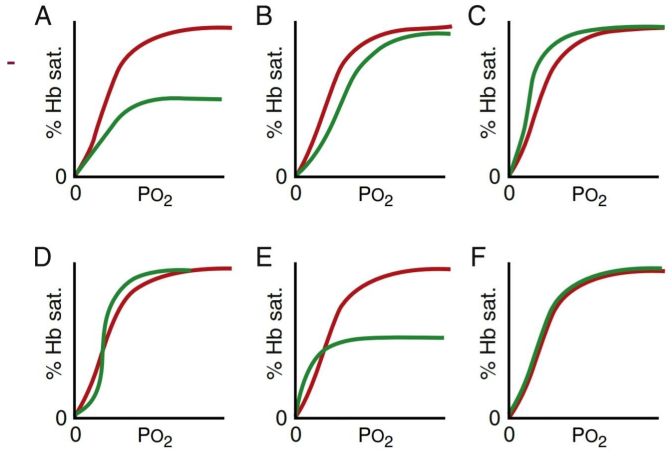
- **O_2 content**: amount of O_2 in blood (ml O_2/100 ml blood)
- **O_2-binding capacity**: maximum amount of O_2 bound to hemoglobin
- (ml O_2/100 ml blood) measured at 100% saturation.

When oxygen binds with hemoglobin , carbon dioxide is released- to increase CO2 transport (in the gas exchange area).

Binding of Hb with O2 at the lung causes the Hb to become a stronger acid (increase H^+) , this in turn displaces CO2 from the blood and into the alveoli (expiration)

Quiz

Questions 1 and 2



1.Which of the above O2-Hb dissociation curves corresponds to normal blood (red line) and blood containing CO (green line)?

A B C D E F

2.Which of the above O2-Hb dissociation curves corresponds to blood from an adult (red line) and blood from a fetus (green line)?

A B C D E F

3- The Haldane effect states that?

A. O2-Hemoglobin binding increases CO2 release
B. O2-Hemoglobin binding decreases CO2 release
C. CO2-Hemoglobin binding increases O2 Uptake
D. Hemoglobin becomes a stronger base

4- Carbon dioxide can be transported as?

A. Dissolved CO2
B. Carbaminohemoglobin
C. Bicarbonate ions
D. All of the above

1.E 2.C 3.A 4.D

SAQS

A man who is anemic has a severely reduced hemoglobin concentration of 10 g/100 mL blood. Assuming that the patient has normal lungs and that the values of both PAO2 and PaO2 are normal at 100 mm Hg, what is the O2 content of his blood, and how does that value compare with the normal value? Assume that for a normal hemoglobin concentration of 15 g/100 mL, the O2-binding capacity is 20.1 mL O2/100 mL blood, and that hemoglobin is 98% saturated at a PaO2 of 100 mm Hg.

Calculate the following:

1.O2 Binding capacity

2.O2 Bound to hemoglobin

3.Dissolved O2 content and total O2 content

O2 binding capacity= hemoglobin concentration(10g/100ml of blood) X measured at 100% saturation(1.34 per each gram)
10X1.34=**13.4 mL O2/100 mL blood**

O2 Bound to hemoglobin=13.4 mL O /100 mL blood × 98%= **13.1 mL O /100 mL blood**

The solubility of O2 in blood is 0.003 mL O2/100 mL/mm Hg. Thus,
Dissolved O2 = 100 mm Hg × 0.003 mL O2 /100 mL/mm Hg = **0.3 mL O2 /100 mL blood**
Total O2 content = O2 bound to hemoglobin + dissolved O2 = 13.1 mL O2/100 mL blood
+ 0.3 mL O2/100 mL blood = **13.4 mL O2/100 mL blood**

Team leaders :

TeiF Almutiri | Abdulaziz Alkraida

Team Members

- Mishal Althunayan
- Basel Fakeeha
- Ibrahim altamimi
- Abdulaziz Alsuhaim
- Mohammad Alkatheri
- Bassam alasmari
- Morshed Alharbi
- Ahmad Alkhayatt
- Mohammod alghedan
- Nawaf alghamdi
- Raed alntaifi
- Homoud alghadeb
- Mishal alhamed
- Musab alamri
- Fayez altbaa
- Khalid altowijeri
- Mohammed alsalman
- Renad Alhomaidi
- Aseel alshehri
- Noura abdulaziz
- Yasmin Al Qarni
- Alaa Alsulmi
- Farah Albakr
- Muneerah alsadhan
- Sarah alobaid
- Farrah alsaid
- Noura almsaud
- Hessah alalyan
- Rema alhdleg
- Raghad alsweed
- Raghad asiari
- Ghadah alouthman
- Haya alanazi
- Asma alamri
- Rania Almutiri
- Yara alasmari

Reviewed by

- Ghadah alouthman
- homoud Algadheb

Contact us

The subleader:
Sarah alQhtani