Oxygen & Carbon Dioxide Transport

Editing File

Color Index:
-Main Text -Important -Notes
-Boy Slides -Girl Slides -Extra

Special Thanks to Hasan Alsughayir for the Sketch <3

Male Dr: Thamir Al-khlaiwi
Female Dr: Aida Korish

Objectives

01 Understand the forms of oxygen transport in the blood and the importance of each form.

02 Differentiate between O2 capacity, O2 content and O2 saturation.

03 Describe (Oxygen- hemoglobin dissociation curve).

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

05 Define the P50 and its significance.

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

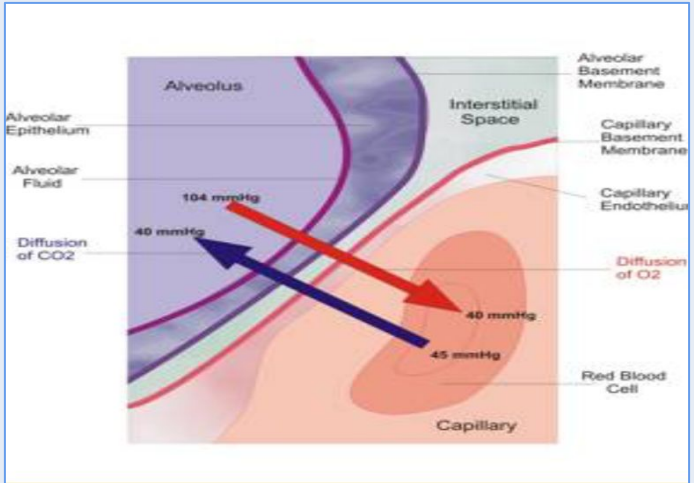
Diffusion capacity of the respiratory membrane

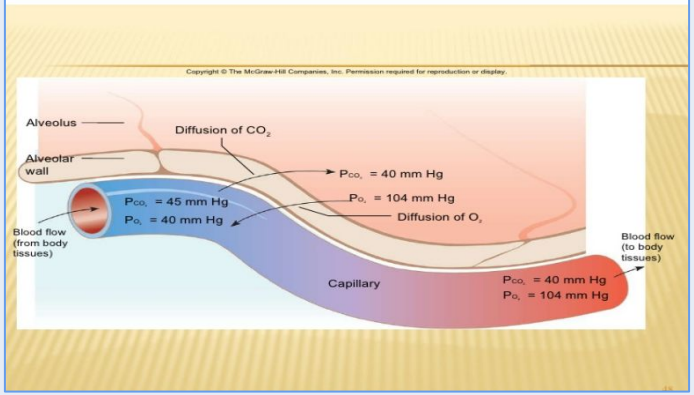
Male Slides Only

01 Is the volume of gas that diffuses through the membrane each minute for a pressure difference of 1 mmHg

02 Diffusing capacity for oxygen at rest : 21 ml/min/mmHg

03 During rest tissues consume 230-250 mlO2 /min
why? If the mean oxygen pressure difference across the respiratory membrane = 11 mmHg and the diffusing capacity for oxygen at rest = 21 ml/min/mmHg 11x21= 230ml oxygen diffusing through the membrane each minute





Male Slides Only

Changes in the oxygen diffusing capacity during exercise

- Diffusing capacity for oxygen during exercises: 65 ml/min/mmHg.

- During exercise, the oxygen requirement increases 20 times, along with cardiac output, so the time blood remains in the pulmonary capillaries becomes less than half normal despite the fact that additional capillaries open up. But the blood is almost completely saturated with oxygen when it leaves the pulmonary capillaries

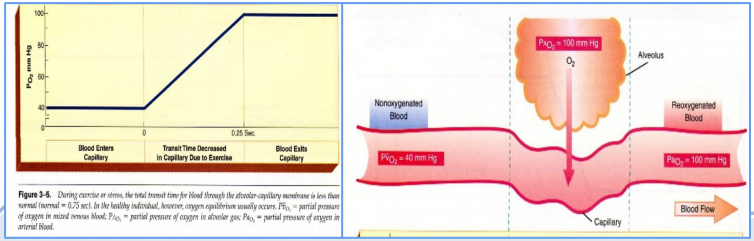


Figure 3-5. *During exercise or stress, the total transit time for blood through the alveolar-capillary membrane is less than normal (normal = 0.75 sec). In the healthy individual, however, oxygen equilibrium usually occurs.* P_{O_2} = *partial pressure of oxygen in mixed venous blood,* $P_{A_{O_2}}$ = *partial pressure of oxygen in alveolar gas;* $P_{a_{O_2}}$ = *partial pressure of oxygen in arterial blood.*

The reasons for this are as follows:

01 The diffusing capacity for oxygen increases almost 3x during exercise, this result mainly from increasing numbers of capillaries participating in the diffusion.

02 At rest the blood stays in the lung capillaries about three times as long as necessary to cause full oxygenation.Therefore, even with shortened time of exposure in exercise, the blood is still fully oxygenated or nearly so.

03 In addition to increased alveolar ventilation.

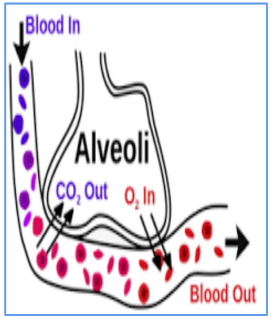
04 Dilatation of the other capillaries.

05 A more even V/Q ratio all over the lung.

Male Slides Only

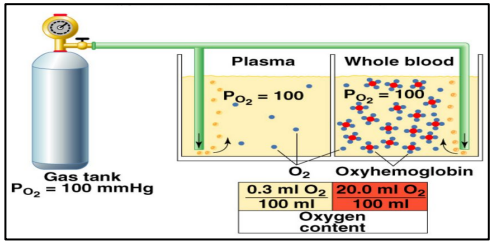
Diffusing capacity of Carbon dioxide

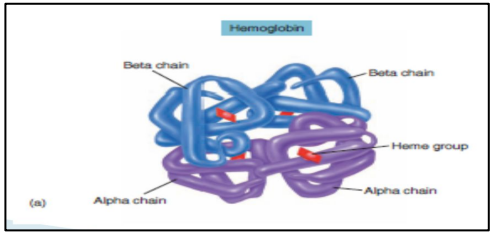
- It Diffuses 20x greater than O2 due to greater diffusion coefficient, which is 20 times that for O2
- Diffusion capacity for carbon dioxide is 200-450 ml/min.
- During exercise the capacity increases to be 1200-1300 ml/min.



Forms of O2 Transport in Blood

- The presence of hemoglobin (Hb) in RBCs allows blood to transport 30 - 100 times as much O2 as could be transported in the form of dissolved O2 in the water of blood.





Forms of O2 Transport in Blood

- Bound to hemoglobin (mostly - 97-98%)
  - Oxyhemoglobin
  - O2 binds to heme group on hemoglobin.
  - 4 O2 / Hb.
  - Increased PO2 → Hb bind to O2.
    Decreased PO2 → Hb release O2.
- Dissolved state (lesser extent - 2-3%)
  - Dissolved in plasma

Terminology

O2 content	Amount of O2 in blood (ml O2 /100 ml blood). equal 19.4 ml
O2 binding capacity (full volume)	Maximum amount of O2 bound to hemoglobin (ml O2 / 100 ml blood) measured at 100% or fully saturation. equal 20ml
Percent saturation	Percentage of heme groups bound to O2 $\%\ \text{Saturation of Hb} = \frac{\text{O2 content}}{\text{O2 binding capacity}} \times 100$ Saturation is usually 98 - 97%
Dissolve O2	Unbound O2 in blood (ml O2 / 100 ml blood) (O2 dissolved in plasma) equal 0.3ml

Any difference in the structure of Hb → many diseases where Hb won't be able to carry O2.

Transport of O2 in Arterial Blood

01

Blood is 100% saturated with O2:

- Each gram of Hb carry 1.34 ml O2
- An adult has 15g Hb/100 ml (dl) blood:
- O2-content / binding capacity = 15 g Hb x 1.34 ml O2
= 20 ml / 100 ml blood (dl) = 20.1ml

هنا راح يتساوى binding capacity و content
لأن الدم 100% مشبع بالاوكسجين فعادي تسمونه أي واحد

02

Blood is 97% saturated with O2:

- Each 100 ml blood contain 19.4 ml O2

97% Because of physiological shunt

03

Amount of O2 released from Hb to tissues: 5 ml O2 / 100 ml blood.

- O2-content* in venous blood at rest = 19.4 ml - 5 ml =14.4 ml

04

During strenuous exercise:

- O2 uptake by tissue increases 3 - 5 folds.
- 15 ml O2 is taken by tissues from each 100 ml (dl) blood . So O2-content in venous blood = 19.4 - 15 = 4.4 ml O2 /dl or /100 ml blood.

الباقي في الوريد هو
ناتج طرح اللي كان في الشريان ناقص اللي راح للنسيج

Transport of O2 in Arterial Blood

05

At rest:
Tissues consume 250 ml O2 /min & produce 200 ml CO2

كم ml O2 من 5L blood ؟
100 ml blood —> 5ml O2
5L blood —> X

$$X = \frac{5000 \times 5}{100} = 250 \text{ ml O2}$$

- Remaining blood in venous return (14.4 ml) is acting as storage of O2 for sudden use (e.g. exercise).

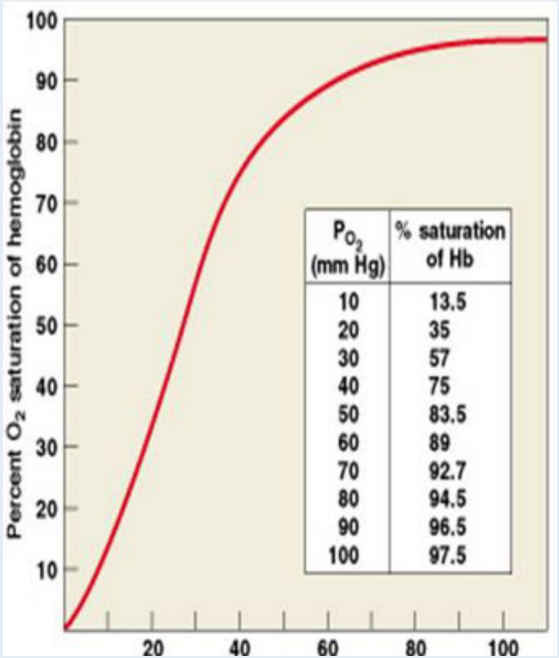
Oxygen Hemoglobin Saturation Curve

01 Higher PO2 → greater Hb saturation with O2.

02 PO2 & Hb-O2 relation is not linear.

03 Oxygen Hemoglobin (Oxyhemoglobin) Saturation Curve or O2 - Hb dissociation Curve

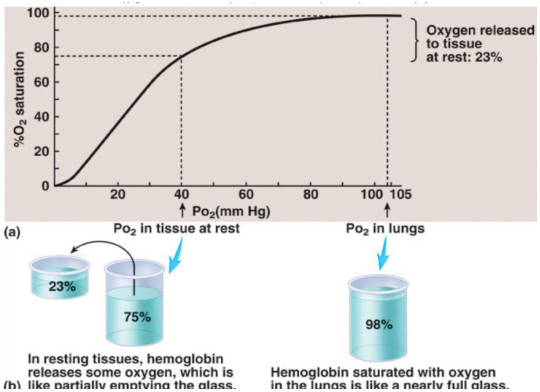
Shape: S - shaped / sigmoid



P_{O_2} (mm Hg)	% saturation of Hb
10	13.5
20	35
30	57
40	75
50	83.5
60	89
70	92.7
80	94.5
90	96.5
100	97.5

Oxyhemoglobin Dissociation Curve

Importance of curve:
Gives indication when Hb is fully loaded & when it is not



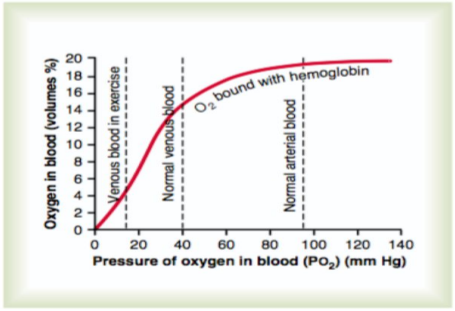


Figure 40–9

Effect of blood P_{O_2} on the quantity of oxygen bound with hemoglobin in each 100 milliliters of blood.

In systemic arterial blood:
Partial pressure of O2
≈ 95 mmHg
containing 19.4 mL of O2

In Venus Return:
Partial pressure of O2 ≈ 40 mmHg
containing 14.4 mL O2 .
(blood after supplying tissue with 5 ml O2)

During Exercise:
Amount of O2 consumption by tissue increases leaving only 4.4 mL O2 in venous return.

Factors Shifting O2-Hb Dissociation Curve

01 The position of dissociation curve can be determined by measuring P50.

02 P50: arterial PO2 at which 50% of Hb is saturated with O2.

03 Normally P50 = 26.5

04 Decreased P50:
- ➔ Increased affinity of Hb to O2
- ➔ Curve shifts to left.

05 Increased P50:
- ➔ Decreased affinity of Hb to O2
- ➔ Curve shifts to right.

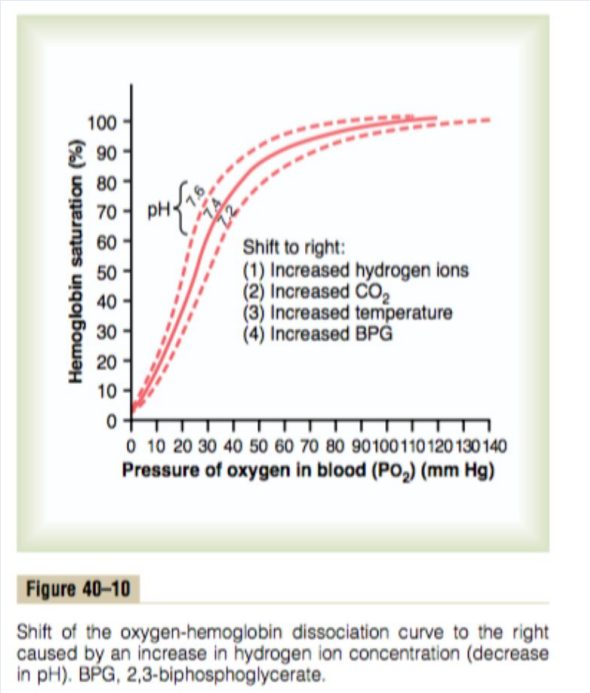


Figure 40–10

Shift of the oxygen-hemoglobin dissociation curve to the right caused by an increase in hydrogen ion concentration (decrease in pH). BPG, 2,3-biphosphoglycerate.

Right & Left Shifts of Dissociation Curve

- If O_2 is Loaded to Hb (from lung)→ left shift.

(during exercise: right shift occurs)

- If O_2 is unloaded to tissues (from Hb) → right shift.

Factors shifting the curve to the right:

1-Increased **2,3 DPG** (facilitate O_2 release):

-Synthesized in RBCs from glycolytic pathway.

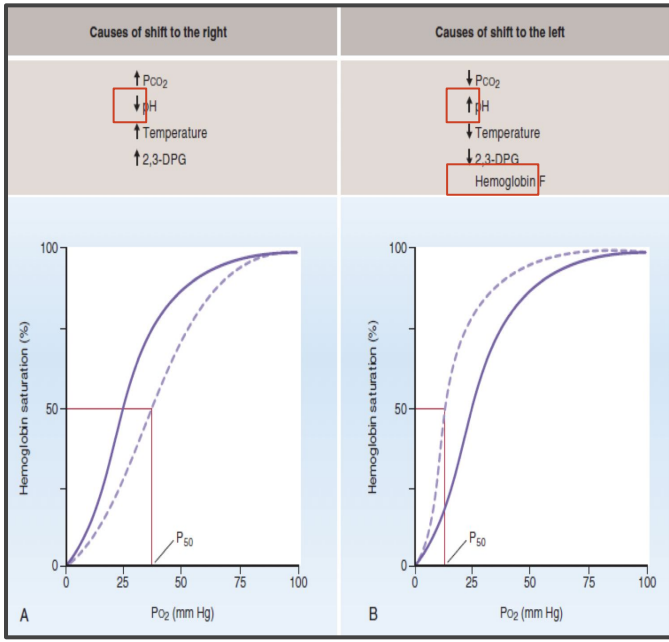
-Binds tightly to reduced Hb.

-Increased in anemia & hypoxemia → serves as an important adaptive response in maintaining tissue oxygenation.

2-Increased H+ (decreased PH)

3-Increased temperature

4-Increased PCO_2



Fetal Hb: has a P50 of 20 mmHg in comparison to 26.5 mmHg of adult Hb. So the curve of fetal Hb is **left shifted**

Bohr effect

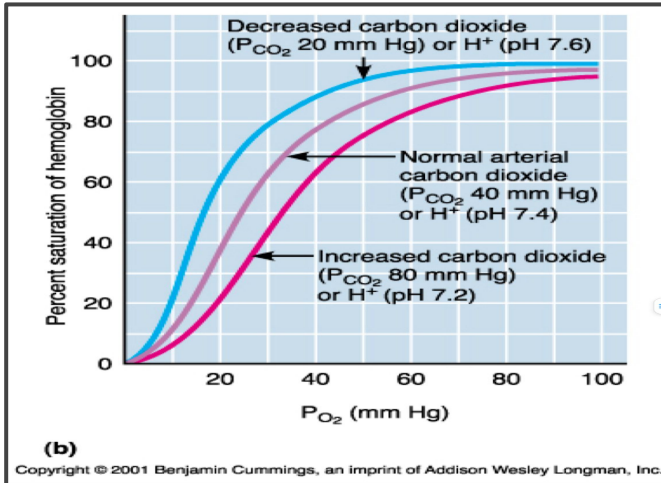
Is the effect of CO_2 & H^+ on the 02-Hb dissociation curve

At lung: CO2 diffuses from blood to alveoli → decrease blood CO2 & H+ → shift curve to left → increase O2 affinity to Hb → more O2 transport to tissues.

At tissue: the reverse occurs

Increased CO2 & H+ produced by tissues during metabolism → shift curve to the right → release/unload O2 from Hb to tissues.

- **Lung:** high PO_2 → increased O_2 affinity & binding with Hb → left shift.
- **Tissues:** low PO_2 → decreased O_2 affinity & binding with Hb→ right shift.



Reminder: PCO_2 & H^+ shift the curve to the right → O_2 is released → tissues get O_2.

Transport of O_2 in Dissolved State

- Only 2-3% of O_2 is transported in the dissolved state. (Tissue consume O_2 directly, and it depends on the PO_2 so higher alveolar PO_2 will increase the amount of O_2 carried in the dissolved state e.g. hyperbaric O_2 therapy as in CO poisoning).

- **At normal arterial PO_2 (95 mmHg):** ~ 0.29 ml of O_2 is dissolved in each 100 ml of blood.

- **When the PO_2 of the blood falls to 40 mmHg in tissue capillaries:** only 0.12 of O_2 remains dissolved.

- Therefore, 0.17 ml of O_2 is normally transported in the dissolved state to tissues per each 100 ml of blood.

Importance of O_2 dissolved: (Extremely important)

➔ Determines PO_2 in blood.

➔ It is the form of Oxygen used directly by tissues.

Dissolve state is important to transport O_2 to places blood can't reach like cornea of eye & cartilage.

Female Slides Only

Shift of Dissociation Curve in Exercise

Exercise increases temperature, H^+, 2,3 DPG → shift the curve to the right.

Utilization Coefficient: percentage of blood that gives up its O_2 as it passes through tissues capillaries.

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

O_2 المستهلك

O_2 الإجمالي

At rest:

Utilization coefficient = 5 ml / 20 ml

Utilization coefficient = 25%

During exercise:

Utilization coefficient = 15 ml / 20 ml

Utilization coefficient = 75 - 85%

20 mL ثابت

Pulse Oximetry

- Pulse Oximetry: a device that measures percent saturation of arterial blood (example: of the finger) using dual-wavelength spectrophotometry.
- Oxyhemoglobin & deoxyhemoglobin have different absorbance characteristics → the
- machine calculates percent saturation from absorbance at two different wavelengths.
- Pulse oximetry measures arterial percent saturation. Why?
  - ➔ Because arterial blood "pulses".
  - ➔ Venous & capillary blood don't "pulse" → background absorbance from venous & capillary blood is subtracted out.
- Pulse oximetry does not directly measure PaO_2. however knowing percent saturation → estimating (تقدير) PaO_2 from O_2-hemoglobin dissociation curve.

Combination of Hb with CO

Displacement of O_2 (CO poisoning)

CO combines with Hb at the same point on the Hb molecule as does O_2.

The affinity of Hb to CO is very high (250 times) compared to O_2,
CO causes poisoning. (استنشاقه خطر جدًا)

CO binds with Hb about 250 times as much as O_2

CO combination with Hb → left shift of the O_2-Hb curve.

CO + Hb → carboxyhemoglobin

CO binds to Hb → Hb is unable to bind with O_2 → hypoxia

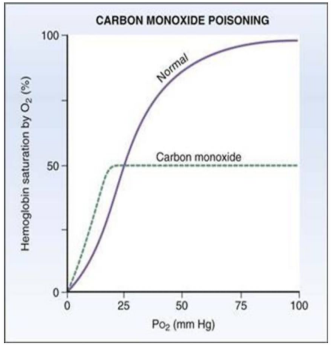


Figure 5–23 Effect of carbon monoxide on the O2-hemoglobin dissociation curve. Carbon monoxide reduces the number of sites available for O2 binding to hemoglobin and causes a shift of the O2-hemoglobin dissociation curve to the left.

Transport of Carbon Dioxide in Blood

Forms of CO_2 Transport in Blood

- Carbaminohemoglobin (CO_2 with Hb ; 23%)
- Bicarbonate ions (HCO_3) (70%)
- Dissolved CO_2 (7%)

(PCO_2 of blood.)

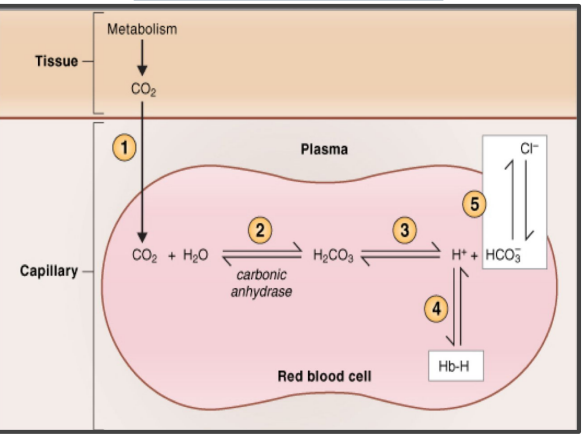
Each 100 ml of blood carry 4 ml of CO_2 from tissues.

Hemoglobin is releasing 5 ml of O_2 to the tissues

Dr's note: اتحاد CO with Hb يسمى Carboxyhemoglobin And it's possible MCQ, So make sure you Know the difference

Formation of HCO^{3-} & Chloride Shift

In tissues



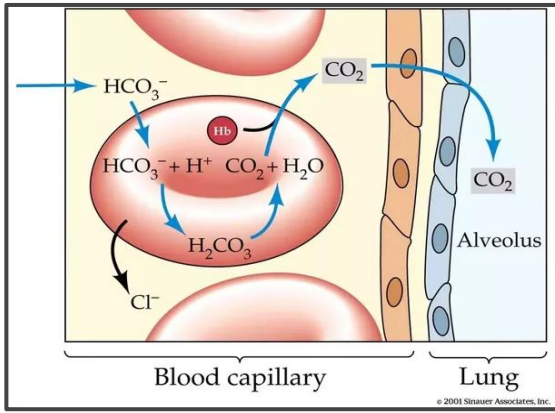
Dr's note: why is the formation of bicarbonate happens only in blood? Cuz it's contain the enzyme (carbonic anhydrase) that is not available anywhere else.

Chloride shift: when HCO_3 (weak acid - easy to dissociate) leaves the RBC → Cl will enters (keep the negatively of RBC in tissue capillary.

أول ما ياخذ الدم الـCO_2 من الـtissues، جزء من الـCO_2 رح يدخل الـRBCs ويرتبط مع ماء وينتج H_2CO_2 بمساعدة الـcarbonic anhydrase. بعدها رح يرتبط الـH_2CO_2 بـH^+ منتجة لنا الـHCO_3^- اللي بيطلع من الدم ويتجه للرئة.

Bicarbonate found in plasma acts as a buffer preventing pH change of blood.

In Pulmonary capillaries



إذا وصلت bicarbonate للرئة، لازم نرجع الـHCO_3^{-1} إلى CO_2 داخل الـRBC: (لأن فيها enzyme اسمه carbonic anhydrase) فيحصل عكس العملية اللي حصلت في tissues يتحد الـHCO_3^{-1} مع الـH^{+1} بمساعدة الإنزيم وينتج H_2CO_2 اللي يتحلل الى ماء بواسطة (dehydration) و CO_2.

The Haldane Effect

Bohr effect: effect of CO_2 on O_2.
Haldane effect: effect of O_2 on CO_2.

O_2 binds with Hb at lungs → CO_2 is released into alveoli → CO_2 transport is increased. (Availability of O_2 facilitated the transport of CO_2)

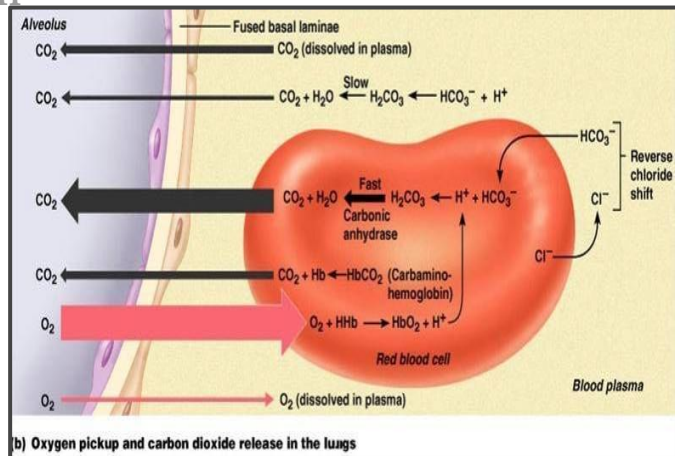
Binding of Hb with O_2 at the lung → Hb becomes a stronger acid → CO_2 is displaced from blood into alveoli.

Change in blood acidity during CO_2 transport:

Change (fall) of 0.04 unit in venous blood due to increased CO_2 in it:

- Arterial blood pH: 7.41
- Venous blood (higher PCO_2): 7.37

Dr's note: Venous blood is more acidic because it's contain CO_2



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

عشان (CO_2 للـalveoli) فبيطلق الـ CO_2 بيكون acid قلنا الـ CO_2، والـHb لما يشبك عليه الـ O_2 ياخذ الـ O_2 مكانه.

قانون: الـacid ما يقدر يرتبط بـacid.

Respiratory Exchange Ratio

(Respiratory Quotient)

$$R = \frac{\text{Rate of } CO_2 \text{ output}}{\text{Rate of } O_2 \text{ uptake}} \quad \frac{4 \text{ ml } CO_2 / 100 \text{ ml blood}}{5 \text{ ml } O_2 / 100 \text{ ml blood}}$$

Normal diet (normally) :
R= ⅘ = 82% =0.825

Carbohydrate diet :
R= 1

Reason:

When O_2 is metabolized with carbohydrates → 1 molecule of CO_2 is formed for each molecule of O_2 consumed.

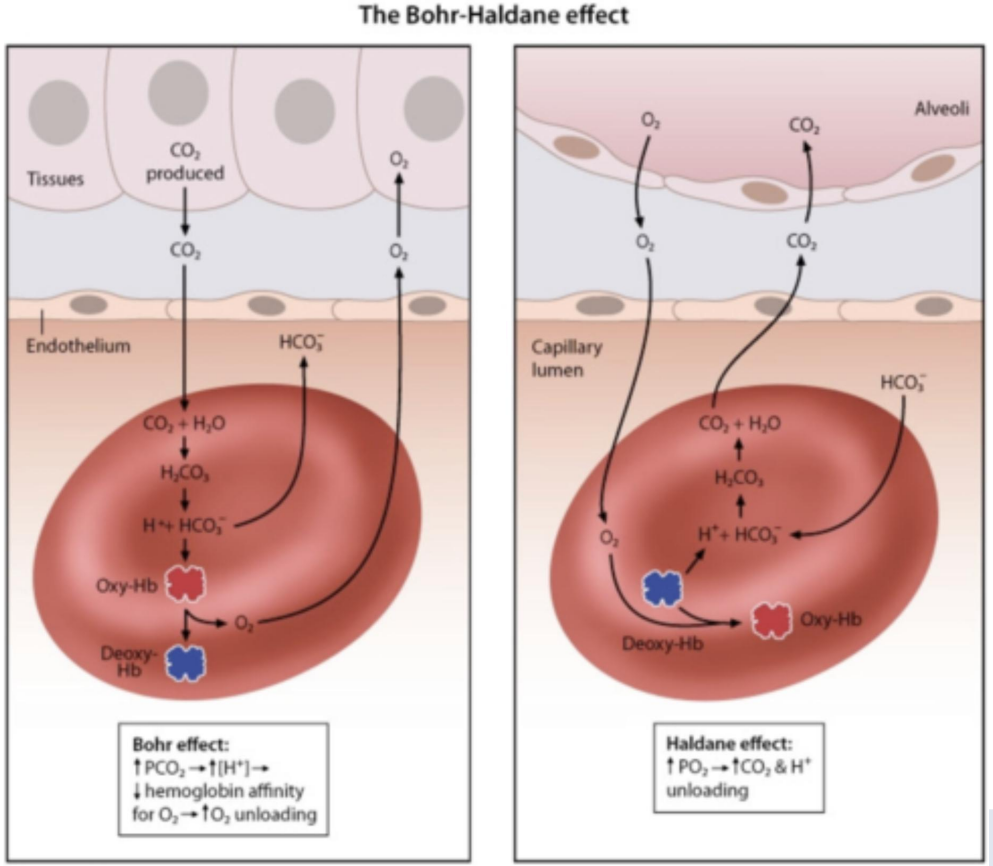
Fats diet :
R= 0.7

Reason:

When O_2 reacts with fats → large share of O_2 combines with H atoms from fats to form water instead of CO_2.

Comparison between Bohr-haldane effects

The **Bohr effect**, describes how carbon dioxide and H+ **affect hemoglobin's affinity for oxygen**.



The **Haldane effect**, on other hand, describes how oxygen concentrations determine **Hemoglobin's affinity for carbon dioxide.**

MCQs

Q1:Which of the following is called Oxyhemoglobin ?			
A-Dissolved O2 in blood	B-Bounded O2	C-Unbounded O2	D-CO2 in blood
Q2:Which of the following causes the dissociation curve to shift to the right ?			
A-Decreased 2,3 DPG	B-Decreased temperature	C-Increased pH	D-increased H+ ions
Q3:Which of the following happens when the dissociation curve shift to the left ?			
A-Loading of O2 on hemoglobin	B-Unloading of O2 on hemoglobin	C-Increase in the PCO2	D-Decreased pH

1-B 2-D 3-A

MCQs

Q4: What is the transport form of CO_2 that has the highest percentage in the blood?			
A-Bicarbonate	B-Carbaminohemoglobin	C-Carboxyhemoglobin	D-Sodium Cholride
Q5:Which of the following is true regarding changes in oxygen transport related to anemia?			
A-Decreased 2,3 DPG	B-Decreased O_2 content	C-Increased pH	D-increased H^+ ions

4-A 5-B

SAQs

Q1: During exercise
a.What will happen to the O2-HB dissociation curve?

b.what are the factors of the change to the curve?

Q2: What is the formula for calculating oxygen content in blood?

A1:
a.It shifts to the right.

b.Increased PCO2 and temperature and 2,3 DPG , decreased PH and O2-Hb affinity.

A2: Oxygen content = Hemoglobin concentration x 1.34 ml O2

Ahmad Addas

Abdulmohsen Alrahaimi

Abdulaziz Nasser

Abdullah Almarwan

Saud Alsaeed

Abdullah Almutlaq

Talal Alrobaian

Khalid Al Tameem

Zyad Alshuhail

Abdulaziz Alobathani

Moath Alabdulsalam

Ibrahim Albabtain

Omar Alattas

Khalid Alkanhal

Leena Shagrani

Marwah Fal

Ghala Alyousef

Rimaz Alhammad

Basma Al-ghamdi

Aljoharah Alyahya

Samiyah Sulaiman

Noreen Almarabah

Aram Alzahrani

Lina Aljameel

Layal Alkhalifah

Hessa Alamer

Aleen Muneif

Farah Aldriweesh

physiology.444ksu@gmail.com