Oxygen and carbon dioxide transport

Respiratory block

PHYSIOLOGY 438 TEAMWORK

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

Editing file

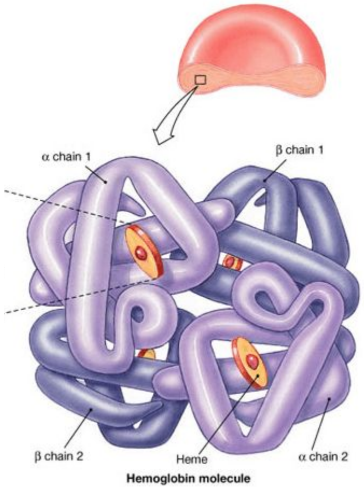
Twitter account

Objectives

1. Understand the forms of oxygen transport in the blood, and the importance of each.
2. differentiate between O_2 capacity, O_2 content and O_2 saturation.
3. Describe the oxygen-hemoglobin dissociation curve.
4. define the P50 and its significance
5. how DPG, temperature, H^+ ions and PCO_2 affect affinity of O_2 for hemoglobin and the physiological importance of these effects.
6. describe the three forms of carbon dioxide that are transported in the blood, and the chloride shift.

Hemoglobin

- oxygen molecules bind loosely and reversibly with Heme portion of Hemoglobin (Heme + Globin)
- The heme portion contains 4 iron atoms, which are capable of carrying 4 O_2 molecules (8 atoms)



Male's slides only

Forms of Hemoglobin

Oxyhemoglobin	Deoxyhemoglobin	Methemoglobin	Carboxyhemoglobin
Normal heme contains iron in the reduced form (Fe2+). Fe2+ shares electrons and bonds with oxygen.	When oxyhemoglobin dissociates to release oxygen, the heme iron is still in the reduced form.	Has iron in the oxidized form (Fe3+). Lacks electrons and cannot bind with 02. Blood normally contains a small amount.	Reduced heme is combined with carbon monoxide, The bond with carbon monoxide is 210 times stronger than the bond with oxygen, which impairs O_2 transport.

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Hemoglobin

Oxygen-carrying capacity of blood determined by its [hemoglobin].	
Anemia:	**Polycythemia:**
[Hemoglobin] below normal.	[Hemoglobin] above normal.
Hemoglobin production controlled by erythropoietin. Production is stimulated by PCO_2 delivery to kidneys.	

Loading/unloading depends:

- PO_2 of environment.
- Affinity between hemoglobin and O_2.

Transport of O_2

- PO_2 and the concentration gradient plays important factor which determines how much oxygen combines with Hb when the haemoglobin (deoxygenated Hb) is converted to HbO_2,
- main function of blood: Transport of respiratory gases between the lungs and body tissues.

If PO_2 is high
As in pulmonary capillaries
→ O_2 binds to hemoglobin and vice versa → Greater Hb saturation

If PO_2 is low
An in the tissue capillaries
→ Hb releases O_2 → Lower Hb saturation

Forms of Oxygen in blood

- **97%** from the lungs to the tissues is carried in chemical combination and get rapidly diffused and binds to hemoglobin
- **3%** is physically being dissolved in plasma

$$Hb + 4O_2 \rightarrow Hb(O_2)_4$$

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Transport of O_2 by haemoglobin:

- Hb combines with oxygen the compound formed is called oxyhaemoglobin, and it depends on the amount of Hb present in the blood.
- Oxygen can combine loosely and reversibly with hemoglobin. **$Hb+O_2$ HbO_2**
- The normal amount of Hb in young adults is about 16 gm/dl of the blood. Each gram of Hb can bind with 1.34 ml of O2 . Thus, 16 x 1.34 = 21.44 ml of O2 /dl.

Partial Pressure Difference:

1. High Partial Pressure of O_2 (Po_2)in Alveoli
2. Low Po_2 in Capillary

Concentration Gradient

- High Concentration of O_2 in Alveoli
- Low Concentration of O_2 in Capillary O_2

Transport O_2:

Diffusion Difference-Very Short → O_2 Diffusion-Very Rapid → O_2 Diffuses from Alveoli Into RBC → (Attaches to Heme Molecule→HbO) → Carried To Tissues

Transport of oxygen in arterial blood

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	When blood is 100% saturated with O_2	When blood is 97% saturated	In venous blood	During strenuous exercise
notes	each gram of Hb carry 1.34 ml O_2	97% of 100% saturation	Amount of oxygen released from the hemoglobin to the tissues is **5ml O_2** per each 100ml blood.	During strenuous exercise the oxygen uptake by the tissue **increases 3 folds** **5ml x 3 folds = 15 ml** O_2 is given /100 ml blood
calculations	Hb x O_2 15g x 1.34	0.97 x 20	O_2 content in 97% saturation – oxygen released to tissue = 19.4 – 5	O_2 content in 97% saturation – oxygen released to tissue during strenuous exercise = 19.4 – 15
oxygen content	20 ml.	19.4 ml.	14.4 ml.	4.4 ml.

★ remember: At rest, tissues consume 250 ml O_2 /min and produce 200ml CO_2

Female's slides only

O_2 capacity, content and saturation

O_2 content	O_2-binding capacity	Percent saturation	Dissolved O_2
Amount of O_2 in blood (ml O_2/100 ml blood)	Maximum amount of O_2 bound to hemoglobin (ml O_2/100 ml blood) measured at 100% saturation	% of heme groups bound to O_2 % saturation of Hb = $\frac{\text{Oxygen content}}{\text{Oxygen capacity}} \times 100$	Unbound O_2 in blood (ml O_2 /100 ml blood)

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Transport of oxygen in the dissolved state

Oxygen in blood

- 97% get rapidly diffused and binds to hemoglobin
- 3% dissolved in plasma

At normal arterial PO_2 = 95 mmHg → 95 x 0.003 → 0.29 ml of oxygen is dissolved in each 100ml of blood.

The solubility of O_2 in blood is 0.003 mL O_2/100 mL/mm Hg (SOLUBILITY factor)

When the PO_2 of the blood falls to 40 mmHg in tissue capillaries → 40 x 0.003 → 0.12 of oxygen remains dissolved

➔ calculation:

from henry's law

$$\text{Partial pressure} = \frac{\text{Concentration of dissolved gas}}{\text{Solubility coefficient}} \longrightarrow \text{concentration of dissolved gas} = \text{partial pressure} \times \text{solubility factor}$$

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

CO_2 transport

Large amount of CO_2 is continuously produced in the body.
In the resting state, 4 ml CO_2 is carried to the lung per 100 ml of blood.

CO_2 is carried in the blood in 3 different forms:

1- 70% of CO_2 is transported in Bicarbonate form (more explanation in the next slide)

2- 7% directly dissolved in plasma

3- 23% of CO_2 binds with deoxyhemoglobin in the RBC (globing part) to form carbamino hemoglobin.

once the blood reaches the pulmonary capillaries, the CO_2 detaches from the hemoglobin and diffuses into the alveoli.

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Factors affecting CO_2 diffusion:

1- Partial Pressure of CO_2 (Pco_2)-Higher In Tissues Than In Capillary

2- Concentration Gradient-CO_2 Higher In Tissues Than In Capillary

3- Distance-Very Short

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CO_2 transport

Bicarbonate form

01 CO_2 is diffused from the tissue to the RBC

02 CO_2 reacts with H_2O in the presence of carbonic anhydrase (speeds up the process) to form carbonic acid

03 Carbonic acid is then dissociated into hydrogen ions (bond with Hb to form HHb) and bicarbonate ions

04 Bicarbonate ions goes into the plasma, and chloride (Cl) ions take its place within the cell to maintain negativity. (chloride shift)

05 Blood is transported to the pulmonary capillaries. Then the bicarbonate ions switch places with the chloride ions present within the RBC.

06 The bicarbonate ions react with the H^+ ions to form CO_2 and H_2O within the RBC.

$$CO2 + H2O \xleftrightarrow{\text{carbonic anhydrase}} H2CO3 \leftrightarrow H+ + HCO3- \rightleftarrows Cl-$$

carbonic acid (H2CO3); bicarbonate ions (HCO3-); membrane; chloride (Cl-)

Transport of CO_2 dissolved in plasma:

Little carbon dioxide 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 CO_2

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

- At the tissues, 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 PULMONARY CAPILLARIES

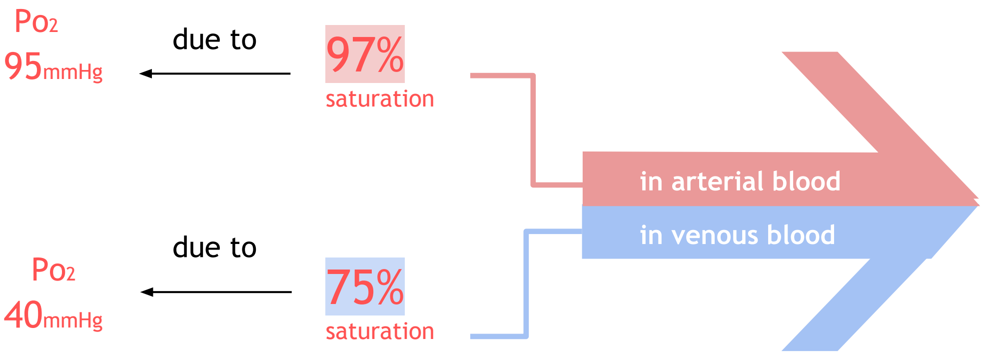
$$H_2O + CO_2\ H_2CO_3\ H^+ + HCO_3^-$$

- 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 $HbCO_2$.

The oxygen-haemoglobin dissociation curve

It's a S-shape or sigmoid (not linear) curve shows:

a. the progressive increase in the percentage saturation of the Hb (Y-axis)
b. with the increase in the PO_2 in the blood (X-axis)



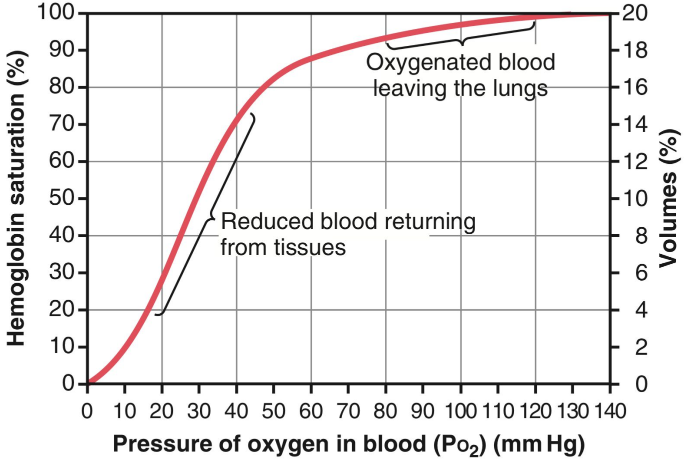
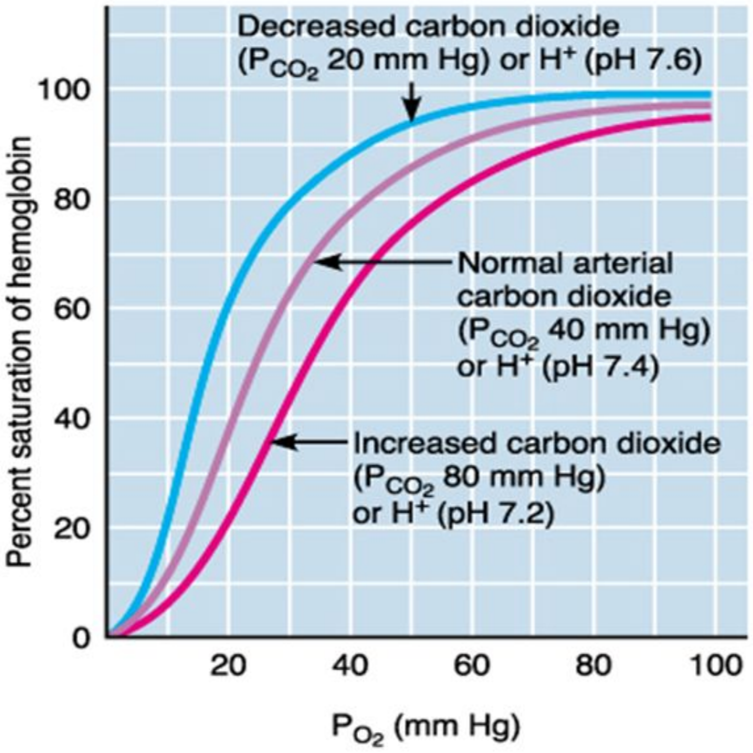


Figure 41-8. Oxygen-hemoglobin dissociation curve.

Factors affecting oxygen-haemoglobin dissociation curve

	Right shift	left shift
Meaning	the oxygen is unloaded to the tissues from Hb	loading or attachment of oxygen to Hb. hemoglobin affinity for oxygen is increased
pH (H^+ conc)	↓ pH ↑ (H^+ conc)	↑ pH ↓ (H^+ conc)
Temperature	↑	↓
(2,3-DPG)	↑	↓
PCO_2	↑ (Bohr effect)	↓
★ P50	↑ (lower affinity for O_2)	↓ (higher affinity for O_2)
Fetal haemoglobin	---	✓



★ **P50:** the partial pressure of O_2 at which 50% of Hb is saturated with O_2.

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

has more affinity for oxygen " why? so the transport of O_2 from mother to the fetus will be easier.

"it

Helpful video

Female's slides only

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

or 2,3-biphosphoglycerate (2,3-BPG)

Synthesis

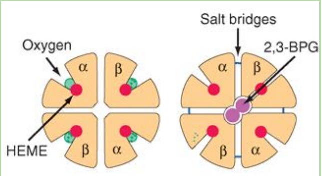
- in RBCs from the glycolytic pathway

★ recall "2,3-BPG Shunt" from the glycolysis lecture in biochemistry

Function

- it binds tightly to reduced Hb.

→ facilitate the oxygen release and shifts the dissociation curve to the right.



Importance

- 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

Bohr effect

★ **At lung:**

Movement of CO_2 from blood to alveoli → decrease blood CO_2 & H^+ → Increase O_2 affinity of Hb → more O_2 transport to tissues

★ **At tissues:**

Movement of CO_2 from tissues to the blood → Increase CO_2 & H^+ in blood → decrease O_2 affinity of Hb → more O_2 transport to tissues

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 O_2 (affinity of Hb to CO is very high that to O_2)

➔ It causes Left shift of the O_2-Hb curve.

★ that's why when someone inhales smoke (Carbon monoxide) he won't be able to breathe.

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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%

★ recall from previous lecture that during exercise it increases up to 3 folds : 5x3=15

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The Haldane effect

The Haldane Effect describes the phenomenon by which binding of oxygen to hemoglobin promotes the release of carbon dioxide. In many ways, the Haldane Effect is the mirror image of the Bohr effect making clear that O_2 and CO_2 compete for hemoglobin occupancy

1. When oxygen binds with hemoglobin, carbon dioxide is released
   ➔ to increase CO_2 transport

2. Binding of Hb with O_2 at the lung causes the Hb to become a stronger acid
   ➔ turn displaces CO_2 from the blood and into the alveoli

3. Change in blood acidity during CO_2 transport.

4. Arterial blood has a PH of 7.41 that of venous blood with higher PCO_2 falls to 7.37 (change of 0.04 unit takes place)

The equation of the Haldane Effect

$$H^+ + HbO_2 \longleftrightarrow H^+Hb + O_2$$

Helpful video

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Respiratory Exchange ratio (Respiratory Quotient)

is the ratio between the amount of carbon dioxide (CO_2) produced in metabolism and oxygen (O_2) used.

$REF= VCO_2/VO_2$

Normally it is 4/5= 82%

When **Carbohydrate** diet is used

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O +$ Energy

$REF= VCO_2/VO_2 \rightarrow 6co_2/6o_2 = 1$

When **fats** only is used

$C_{16}H_{32}O_2 + 23O_2 \rightarrow 16H_2O + 16CO_2 +$ Energy

$REF= VCO_2/VO_2 \rightarrow 16co_2/23o_2 = 0.7$

A person on normal diet R= 0.825 (the average)

Quiz

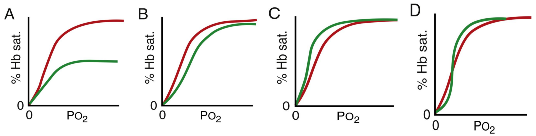
You don't understand why we choose this answer? Click here to read the explanations

1-Blood gas measurements are obtained in a resting patient who is breathing room air. The patient has an arterial content of 19 ml O_2/min with a PO_2 of 95. The mixed venous O_2 content is 4 ml O_2/100 ml blood. Which condition does the patient have?

A. An increase in physiological dead space
B. Pulmonary edema
C. A low Hb concentration
D. A low cardiac output

2- CO_2 is transported from the tissues to the lungs predominantly in the form of bicarbonate ion. Compared with arterial red blood cells, which of the following options best describes venous red blood cells?

	Intracellular Chloride Concentration	Cell volume
A.	Increased	Decreased
B.	Decreased	Increased
C.	No change	Decreased
D.	Increased	Increased



Use these diagrams to answer 3rd&4th questions

3-Which of the O_2-Hb dissociation curves corresponds to blood from an adult (red line) and blood from a fetus (green line)?

A. A
B. B
C. C
D. D

4- Which of the above O_2-Hb dissociation curves corresponds to blood during resting conditions (red line) and blood during exercise (green line)?

A. A
B. B
C. C
D. D

SAQ

1- what are the factors shifting oxygen-haemoglobin dissociation curve to the right?

2- what are the types of O_2 in the blood?

Answers

1- 1) Decreased pH or (increased H+ conc), 2) increased temperature, 3) and the increased concentration of 2,3 diphosphoglycerate (2,3-DPG). 4) increased PCO2 concentration (Bohr effect) all shift the curve to the right.

2- - 3% dissolved in plasma
- 97% bound to hemoglobin (oxyhemoglobin)

Key answers:

1-D 2-D 3-C 4- B

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