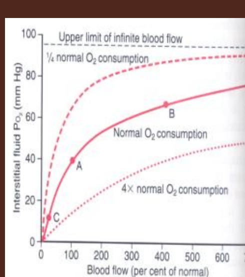
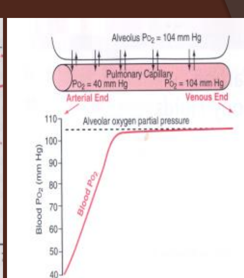
Oxygen and Carbon dioxide Transport

Objectives

- 1- Understand the forms of oxygen transport in the blood, the importance of each fo
- 2- Describe: -(Oxygen- hemoglobin dissociation curve)
- b- How DPG, temperature, H^+ ions and PCO_2 affect affinity of O_2 for Hemoglobin and the physiological importance of these effects.
- 3- Differentiate between O2 capacity, O2 content and O2 saturation.
- 4- Define the P50 and its significance.
- 5- Know the significance of fetal Hb and adult myoglobin.
- 6-Describe the three forms of Carbon dioxide that are transported in the blood, and the chloride shift.
- 7- Describe the role of the enzyme carbonic anhydrase, and the CO_2 dissociation curve.
- 8- Define respiratory acidosis and respiratory alkalosis, and explain how these are related to hypoventilation and hyperventilation respectively.

Oxygen uptake by pulmonary capillary blood





Diffusion of oxygen from the capillaries to the intestinal fluid

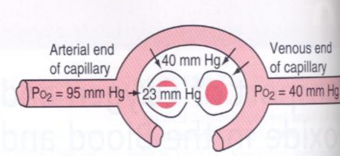
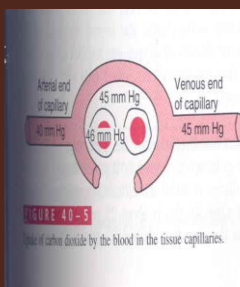
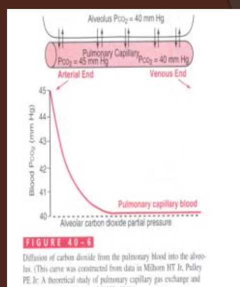


FIGURE 40-3

Diffusion of oxygen from a tissue capillary to the cells.

Diffusion of CO2 from the cells to the tissue capillaries, and from the pulmonary capillaries to the alveoli





Transport of oxygen and carbon dioxide in the blood and body fluids

Key Concepts

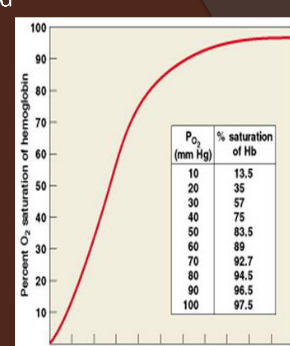
- O_2 mostly transported in blood bound to hemoglobin
- If the P_{O2} increases Hb binds O_2
- If P_{O2} decreases Hb releases O_2
- CO_2 mostly transported in blood as HCO_3^-
- Lesser amounts of CO_2 are bound to Hb or dissolved in plasma

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: % of heme groups bound to O_2
- Dissolved O_2: Unbound O_2 in blood (mL O_2/100 mL blood)

Oxygen transport in Blood

- Oxygen transport
  - 3% dissolved in plasma
  - 97% bound to hemoglobin (oxyhemoglobin)
- Oxyhemoglobin Saturation Curve :
  - higher P_{O_2} results in greater Hb saturation



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

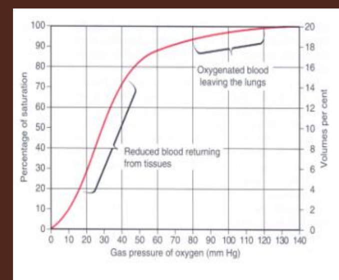
Function of hemoglobin to transport oxygen in arterial blood

- *Oxygen content* (20 ml O2 /dl blood) each ml of Hb carry 1.34 ml O2 (15 x 1.34=20) this is when Hb is 100% saturated with O2.
- but when the blood is only 97% saturated with O2 each 100 ml blood contain 19.4 ml O2).
- Amount of oxygen released from the hemoglobin in the tissues (5ml O2 is given to the tissues per each 100ml blood (19.4-5= 14.4 ml).
- *Transport of oxygen during strenuous exercise.*

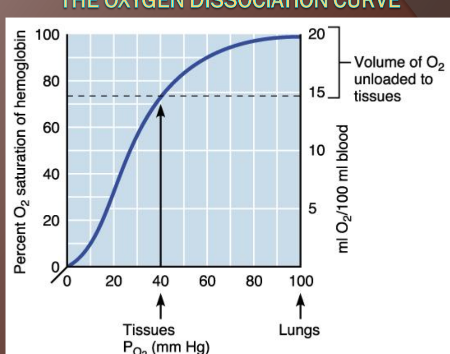
  The oxygen uptake by the tissue increases 3 folds so 15 ml O2 is given /100 ml blood (19.4-15=4.4 ml O2 /100ml blood).

  Tissues consume 250 ml O2 /min at rest and produce 200ml CO2

Oxygen-Hb dissociation curve



THE OXYGEN DISSOCIATION CURVE



Oxygen hemoglobin dissociation

- **Method;** blood is put in different tubes (tonometers) and exposed to oxygen at different pressures (PO2) and let to rotate at body temp in water path).
- **Then the *oxygen content* in each tonometer is measured.**
- In a separate tonometer we expose the blood to very high PO2 (600 mmHg0, the amount of Hb that combines with oxygen at this very high O2 tension is **called *oxygen capacity***

Cont.. O2-Hb dissociation

- % saturation of Hb
  = oxygen content x 100
  oxygen capacity
- the relation between PO2 and Hb-O2 is not linear. The curve is S- shaped or sigmoid
- the presence of one molecule of oxygen on one hem group increases the affinity of the other oxygen binding sites to O2.

Effect of blood PO2 on the amount of %HbO2

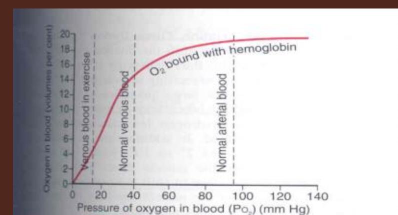


FIGURE 40 – 9
Effect of blood P_{O_2} on the quantity of oxygen bound with hemoglobin in each 100 milliliters of blood.

Factors that shift the O2- Hb dissociation curve

- The position of the dissociation curve can be determined by measuring the P50
- **P50:-** the arterial oxygen tension at which 50% of the Hb is saturated with O2, normally P50= 26.5
- 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.

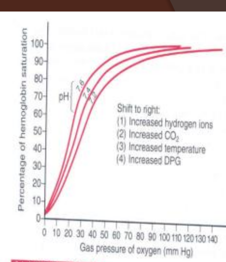


FIGURE 40 – 10
Shift of the oxygen-hemoglobin dissociation curve to the right by increases in (1) hydrogen ions, (2) CO_2, (3) temperature, or (4) 2,3-diphosphoglycerate (DPG).

The Rt and Lt shifts:

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

Effect of *2,3DPG*, effect of *temperature*↑ cause shift to Rt.

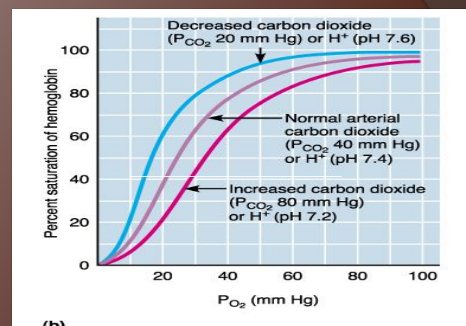
- 2,3DPG; is synthesized in RBCs from the glycolytic pathway , it binds tightly to reduced Hb. increased 2,3 DPG facilitate the oxygen release and shifts the dissociation curve to Rt.
- 2,3 DPG increases in the RBCs in anemia and hypoxemia, and thus serves as an important adaptive response in maintaining tissue oxygenation
- *Fetal Hb: has a P50 of 20 mmHg in comparison to 27 mmHg of adult Hb.*

Effect of *carbon dioxide* and *hydrogen ions* on the curve (*Bohr effect*)

* 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 occur

BOHR EFFECT



Bohr Shift Curve

Shift of dissociation curve during exercise

- Temp, H+, 2,3 DPG, increases 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.*

  = <u>O2 delivered to the tissues</u>
  O2 content of arterial blood
- *Normally at rest = 5ml/20 ml= 25% , during exercise it = 15 ml/20 ml= 75 % - 85%*

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

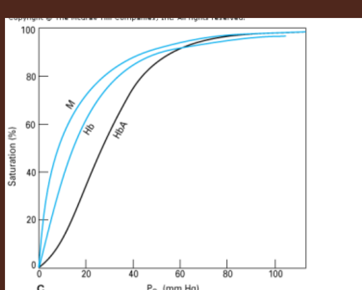
Combination of Hb with CO —— displacement of oxygen

- 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 Lt shift of the O2-Hb curve.

Fetal Hb and methemoglobin

- **Fetal hemoglobin (hemoglobin F, Hb)**
- the two β chains are replaced by γ chains, giving it the designation of $\alpha_2\gamma_2$.
- hemoglobin F has a **higher affinity for O_2** than hemoglobin A, facilitating O_2 movement from the mother to the fetus.
- is replaced by hemoglobin A within the first year of life.
- Myoglobin:a heme protein that occurs naturally in muscle cells, consists of a single polypeptide chain attached to a heme group. It can therefore combine chemically with a single molecule of oxygen and is similar structurally to a single subunit of hemoglobin

Dissociation curve for fetal Hb, Myoglobin



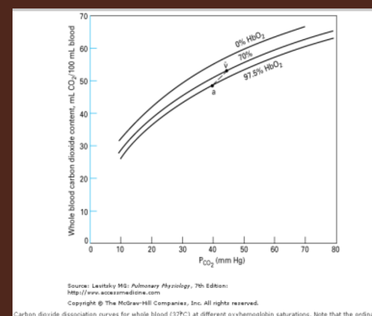
Cont.. Myoglobin

- the hyperbolic dissociation curve of myoglobin (which is similar to that of a single hemoglobin subunit) is far to the left of that of normal adult hemoglobin.
- That is, at lower P_{O2}s, much more oxygen remains bound to myoglobin.
- Myoglobin can therefore act to transport and store oxygen in skeletal muscle. As blood passes through the muscle, oxygen leaves hemoglobin and binds to myoglobin. It can be released from the myoglobin when conditions cause lower P_{O2}s.

Transport of carbon dioxide in the blood.

- **Chemical forms in which carbon dioxide transported.**
- *Dissolved CO2 7%*
- *bicarbonate ions 70 %*
- *Carbaminohemoglobin (with Hb).23%*
- each 100 ml of blood carry 4 ml of CO2 from the tissues/min .

CO2 Dissociation curve for whole blood

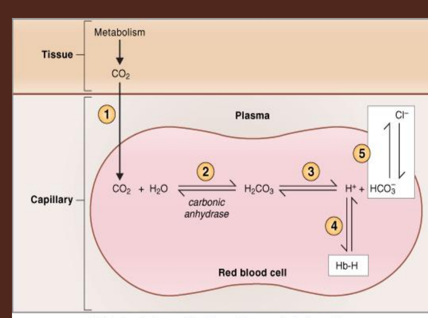


How does the shape of the oxygen dissociation curve differ from the CO2 dissociation curve?

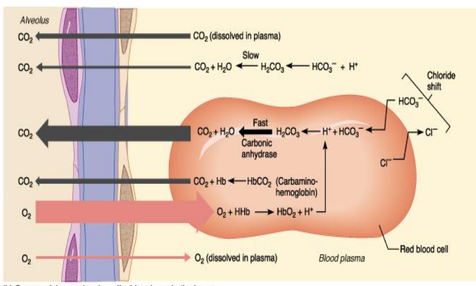
- The CO2 dissociation curve is

  curvi-linear
- The O2 dissociation curve is *sigmoidal*
- That is, there is a greater change in CO_2 content per mm Hg change in P_{CO2} than there is in oxygen content per mm Hg change in P_{O2}

Formation of HCO3– & Chloride shift inside RBC



CHLORIDE SHIFT IN PULMONARY CAPILLARIES



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

H^+ transport in the blood

- H^+ must be buffered so that the pH of the red blood cells (and the blood) remains within the physiologic range.
- The H^+ is buffered in the red blood cells by deoxyhemoglobin and is carried in the venous blood in this form.

The Haldane effect

- *When Oxygen binds with hemoglobin , carbon dioxide is released- to increase CO2 transport*
- *Binding of Hb with O2 at the lung causes the Hb to become more a stronger acid and , this in turn displaces CO2 from the blood and into the alveoli*
- ***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*

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

- 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