Physiology
of the
Respiratory system
Lecture 3

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Gas transport in the blood

Transport of oxygen

O2 is transport in the blood in 2 forms:-

a) Dissolve in plasma (2%)

b) Bound to haemoglobin (98%)

Dissolved oxygen

It equal to Solubility of $O_2 \times PO_2$

Solubility of O_2 =0.003ml/100 ml blood/mmHg

- PO_2 =100 mmHg (in arterial blood)and 40 mmHg (in venous blood)
- Therefore dissolved O_2 in 100 ml arterial blood =100×0.003=0.3 ml 0_2/100ml blood
- Dissolved O_2 in 100 ml venous blood = 40×0.003=0.12 ml 0_2/100ml blood

- Remember that PO2 in arteries (Pa02) is actually less than 100mmHg (=95mmHg) because of physiological shunt.

Oxygen bound to hemoglobin:-

- ✓ O_2 bind to Hb in a rapid reversible oxygenation reaction (iron remain in the ferrous state)
- ✓ The reaction takes less than 0.01 sec
- ✓ Each gram of Hb can carry up to 1.34ml O_2

(if 100% saturated as in arteries)

O_2 bound to Hb in arterial blood can be calculated as follows: -

- $O2=[Hb]\times1.34\times[\%\ \text{saturation of Hb with oxygen}]$
- $[Hb]=15g/100ml$ blood

Therefore $O_2=15\times1.34\times100\%=$ 20ml O_2/100ml blood

Oxygen bound to Hb in venous blood can be calculate as follow:-

- $O_2=[Hb]\times1.34\times[\%\text{saturation of Hb with } O_2]$
- Hb=15 g/dl
- Therefore $O_2=15\times1.34\times75\%=15$ ml O_2/100ml blood

- The relation between PO_2 and percent blood saturation of Hb with O_2 is explained by the ***oxygen–hemoglobin dissociation curve***

Oxygen–hemoglobin dissociation curve

- This curve indicates direct relation between PO2 and % saturation of Hb with O2

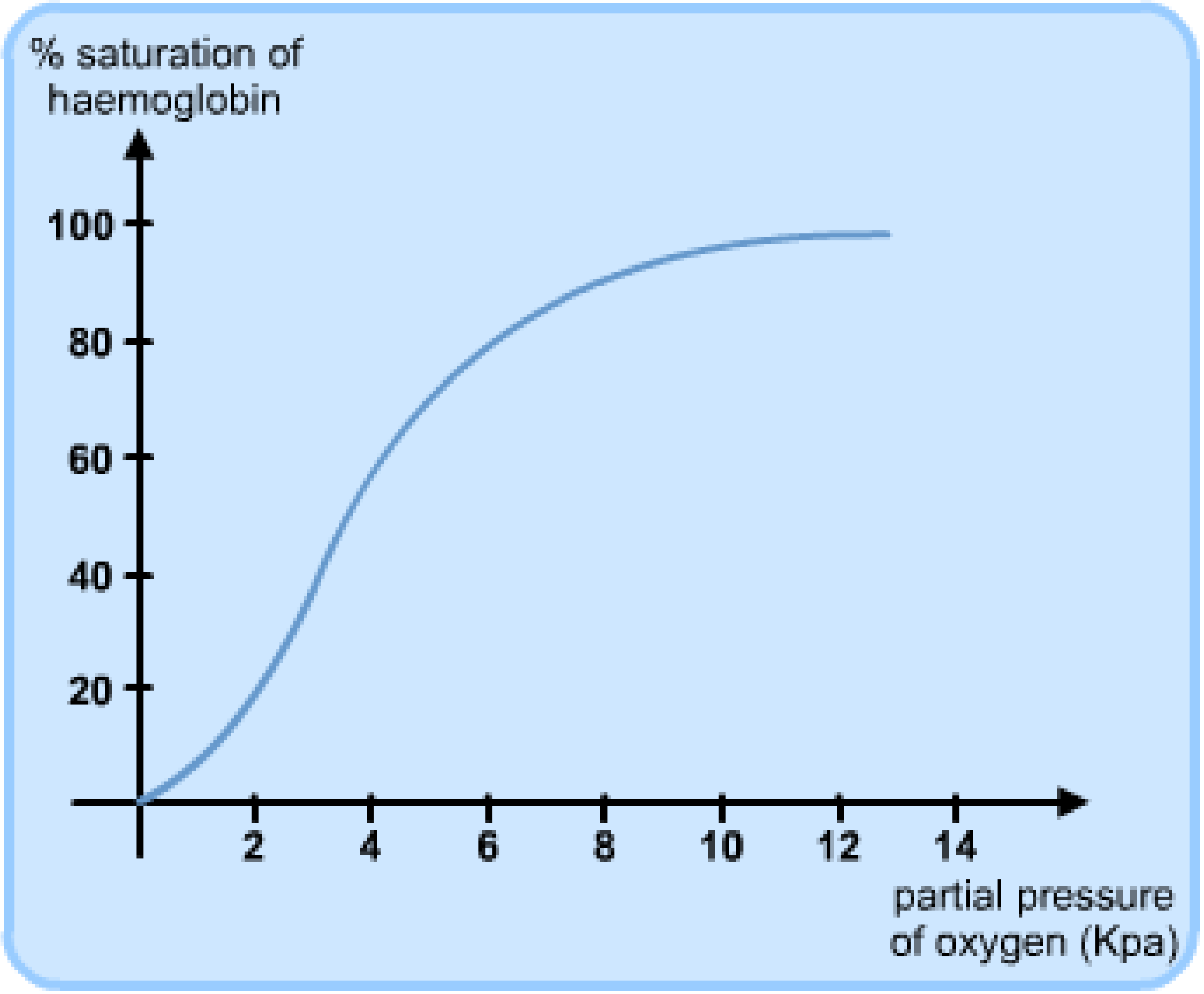
- The sigmoid shaped (start slowly, become steep in the middle and then reaches the maximum)

The sigmoid shape is explained by: -

1) O_2 bind to subunit of Hb successively (not all of them at the same time)

2) The binding with the first subunit facilitates binding with the second subunit and this facilitates binding with the third subunit and so on…

3) The facilitation occur due change in the configuration of Hb from tense (T) form to the relaxed (R) form.


% saturation of haemoglobin
100
80
60
40
20
2
4
6
8
10
12
14
partial pressure of oxygen (Kpa)

Therefore binding:-

i. **Start slowly:** indicating low affinity of Hb to oxygen (occurs when oxygen is binding to the first subunit).

ii. **Becomes steep** in the middle: indicating high affinity of Hb (occurs when oxygen is binding to other subunits) the affinity is increased up to 500 folds.

iii. **Reach maximum** at the end (indicating full saturation).

Notes to remember from the curve

- PO_2 of 40 mmHg gives oxygen saturation of 75 %(as in veins).
- PO_2 of 95 mmHg gives oxygen saturation of 97 %(as in arteries).
- PO_2 of 97mmHg gives O_2 saturation of 97.5% (as in oxygenated blood in pulmonary venous capillaries). Less saturation in arteries (0.5%) is due to physiological shunt.
- PO_2 of 26mmHg gives O_2 saturation of 50%. (this is known as the $\mathbf{P_{50}}$)

- **P_{50}** is defined as the PO_2 when Hb is 50% saturated with O_2 It is used to describe the affinity of Hb to O_2 (e.g. high **P_{50}** indicate low affinity of Hb to O_2 whereas low **P_{50}** indicates the reverse.)

Affinity of Hb to oxygen

– the affinity of Hb to oxygen is affected by certain factors ,these factors can shift the curve to the right or to the left.

– the **P_{50}** gives information about affinity of Hb to O_2.Normal value=26mmHg ;higher values indicates shift to the right (low affinity) and lower values indicates shift to the left (high affinity).

☒ ***Shift to the right***

- Indicate lower affinity of Hb to O_2 (high $\mathbf{P_{50}}$).
- Indicate increased release of O_2 to tissues.
- **Caused by:-**

  - High carbon dioxide
  - Low pH (high hydrogen ions)
  - High 2,3 DPG
  - High temperature

2,3 diphosphoglycerate (2,3 DPG) is product of glycolysis , it is highly present in RBCs when metabolism is increased. It is also increased in exercise, high altitude and by some hormones like growth hormone, thyroid hormones and estrogens. Its binding to the beta chain of Hb decreases the binding of Hb to oxygen.

The ease with which haemoglobin releases oxygen to the tissues is controlled by erythrocytic **2,3-diphosphoglycerate** (**2,3-DPG**) such that an increase in the concentration of **2,3-DPG** decreases oxygen affinity and vice versa.

☒ *Shift to the left*

- Indicate increased affinity of Hb to O_2 (low $\mathbf{P_{50}}$).
- Indicate decrease release of oxygen to tissues.
- **Caused by:-**
  - Low carbon dioxide
  - Low hydrogen ions(high PH)
  - Low 2,3 DPG [e.g. due to acidosis(with high anion gap) or in stored blood]
  - Low temperature
  - Myoglobin and Haemoglobin F

Remember that: –

- ✓ Shift to the right occur in tissues, where CO_2, H^{+1} and temperature are high whereas shift to the left occurs in the lung where these factors are decreased.

- ✓ Hb F and myoglobin have very high affinity to oxygen. They shift the curve to the left.

- ✓ Hb F binds less avidly to 2, 3 DPG this increase it's affinity to O_2.

- ✓ Anemia does not affect the shape of the curve because PO_2 is normal and therefore the% saturation of Hb is normal.

Bohr effect: -

- The affinity of Hb to O_2 is decreased when the PH of the blood decrease.
- That is why increase in CO_2 content of the blood decreases the affinity of Hb to O_2 causing shift of the curve to the right.

Transport of CO2:-

CO_2 is transported in 3 forms:–

- ❖As bicarbonate(the main form of transport)
- ❖Bound to proteins(carbamino compound)
- ❖Dissolved.

Dissolved CO_2

- The solubility of CO_2 is higher than O_2 (up to 20 times).
- The dissolved CO_2 constitutes about 5% of total CO_2 in arterial blood and 6% of total CO_2 in venous blood.
- Generally there is no reaction between CO_2 and water in the plasma (due to the absence of *carbonic anhydrase* enzyme in the plasma).

Transport of CO_2 as bicarbonate

- This is the main form of CO_2 transport in the blood.

- CO_2 diffuses inside RBCs and react with water in the presence of *carbonic anhydrase enzyme* to produce carbonic acid and then bicarbonate and hydrogen ion.

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

  - Hydrogen ions are buffered by haemoglobin.
  - About 70% of bicarbonate diffuse to the plasma in exchange to chloride (=chloride shift).

Remember that:-

- Due to diffusion of CO_2 into RBCs, the number of active osmatic particles in RBCs is increased by either $HCO3^-$ or cl^- .
- So in venous blood, water enters RBCs by osmosis, increasing the size of RBCs. Then it passes out in the lung; when chloride leaves out and the RBCs return to their normal size in arteries.
- That is why PCV of venous blood is higher than arterial blood by about 3%

CO2 bound to proteins

- CO_2 form carbamino compound by binding to proteins (plasma proteins in plasma and Hb in RBCs)
- About 11% of CO_2 in the blood is carried to the lungs as carbaminoCO_2

Haldane effect

- DeoxyHb in venous blood binds CO_2 more readily than oxy Hb in arterial blood.
- Therefore binding of oxygen to Hb in the lungs facilitates release of CO_2 from Hb ,this is known as the Haldane effect
- for this reason arteries (containing oxygenated blood)carry less CO_2 than veins(containing deoxygenated blood).

☒In summery

CO_2 is transported in plasma as:-

- Dissolved
- Carbamino–CO_2
- HCO_3
- **CO_2 is transported in RBCs as:-**
- Dissolved
- Carbamino Hb
- HCO_3

- About 70% of HCO_3 enters the venous blood in exchange to chloride (chloride shift)
- ✓ PCV of venous blood is higher than arterial blood by about 3%

To be continued once again……