CO2 TRANSPORT (CARRIAGE) BY THE BL00D

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CBU SCHOOL OF MEDICINE

❑Depending on the PC02 level, *C02 flows downhill* from the tissues to the blood, then to the lung alveoli, where it is eliminated outwards.

❑CO2 IN THE ARTERIAL BLOOD

❑The arterial blood normally contains about 49 ml C02 /dL (100ml) which are present in the following forms:

1. In physical solution (dissolved in the plasma and RBCs)

This is free C02 and it constitutes only about 5 % of the total C02 content in the arterial blood (about 2. 6 ml %). However, it is important since <u>it determines the arterial PCO2 (normally about 40 mmHg)</u>.

2. In reversible chemical combination

This constitutes about 95% of the total C02 content in the arterial blood (about *46.4 ml* %), and is present in the following 2 forms:

a- Bicarbonate (HCO3) : This is present as KHC03 in the red blood cells and NaHCO3 the plasma, and it constitutes about 90 % of the total C02 content in the arterial blood (about 43.8 ml %).

b- Carbamino compounds : These constitute 5 % of the total C02 content in the arterial blood (about *2. 6 ml* %) and are formed by combination of C02 to the amino groups of the amino acids in the proteins (forming *R.NHCOOH,* where R is the protein).

- Some C02 combines to the plasma proteins, but the majority combines to Hb forming Hb.NHCOOH (carbHb).

Importance of the high arterial C02content

- C02 forms an *important buffer system (HCO3-I H2C03)* that antagonizes changes in the blood pH. In the arterial plasma, the ratio HC03- *I* H2C03 is normally 20:1, and *the arterial blood pH is kept constant at 7.4 as long as this ratio is not changed.*

THE TIDAL C02

- This is the volume of C02 that is added to each I00 ml of arterial blood during its flow through the tissues.

- It is normally about 3.7ml during rest, and 1t increases the C02 content in the venous blood to *52.7 ml/dL* and the PCO2 to about *46 mmHg*

- It is transported in the same proportions as the C02 already present in the arterial blood (i.e. *mostly in the chemical form)* so as to keep the ratio HC03· / H2C03 unchanged and the blood pH constant at 7.4.

- Accordingly, it is transported as follows :

1. 10% (0.4 ml) remain in the *physically dissolved form* equally in the plasma and the red blood cells (5 % each)

2. 90% (3.3 ml) is transported in *2 chemically-combinated forms :*

a- 25 % (0.8 ml) as carbamino compounds, mostly carbHb. Binding of C02 to the proteins is rapid and requires no enzymes or other catalysts and the reduced Hb forms more carbHb than oxyHb.

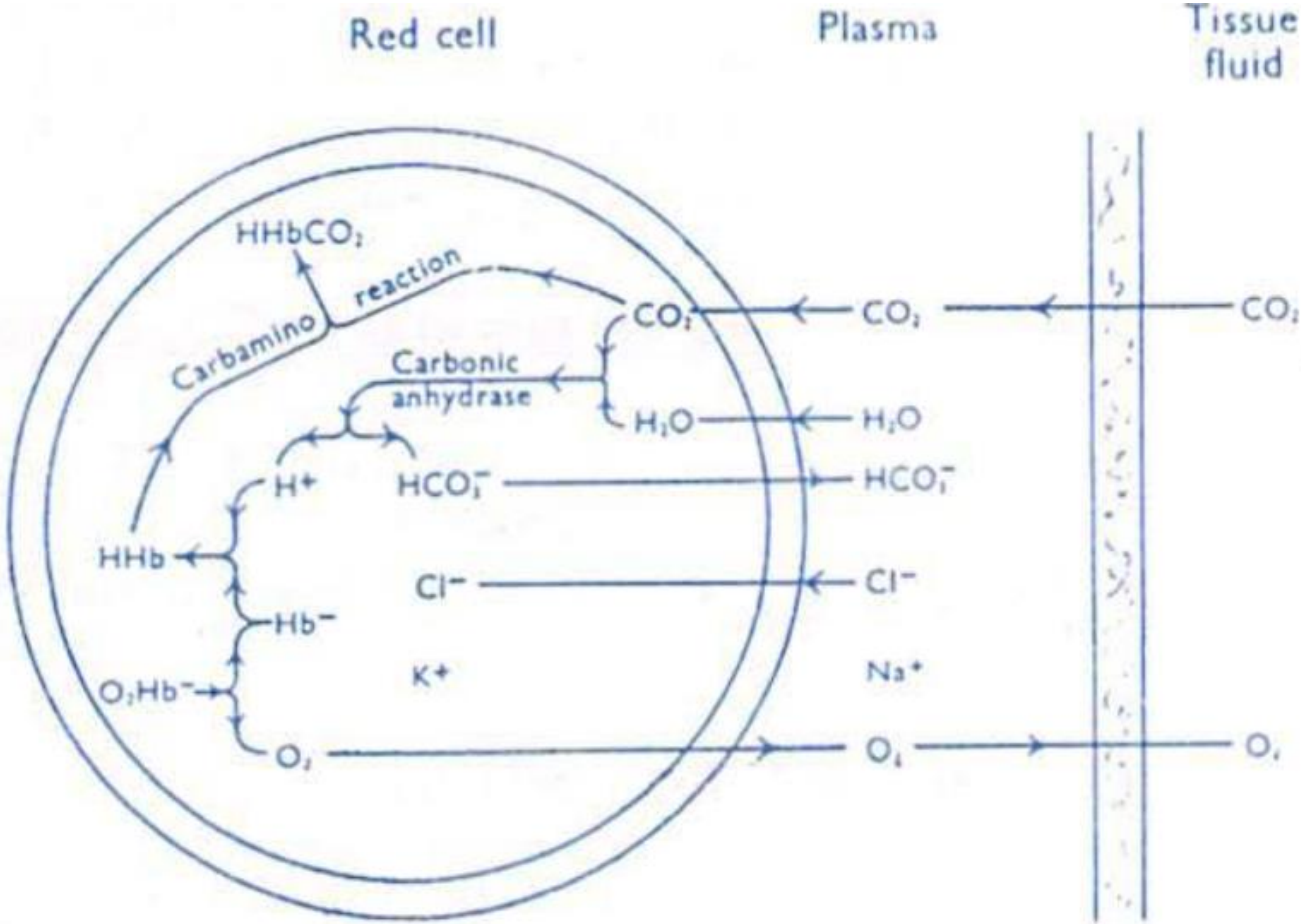
b- 65% (2.5 ml) as bicarbonate ions (HC03-) , in both the red blood cells (60 %) as well as the plasma (5 %)

Mechanism of formation of HC03 (role of carbonic anhydrase)

- HCO3 is formed by hydration of C02 to H2C03 then dissociation of the latter into H+ and HC03- as follows:

$$CO_2 + H_2O \xleftrightarrow{\text{carbonic anhydrase}} H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

- The hydration reaction is accelerated by the carbonic anhydrase enzyme which is present only in the red blood cells.For this reason, 60% of HCO3 is formed in the red cells and only 5% in the plasma



Buffering of CO_2 in the red blood cells. Notice the Cl⁻ shift

Fate of HC03 in the plasma and red blood cells

- The formed HC03- in the plasma combines with Na^+, forming $NaHCO_3$. Inside the red blood cells, about 30% of the formed HCO_3^- combine with K, forming KHC03 while 70% diffuse into the plasma and combine with Na^+ forming NaHC03.

- To maintain electric neutrality, other - ve ions diffuse from the plasma into the red blood cells and combine with K-. These are mostly Cl^- so the process is called chloride shift .

Sources of K+ inside the red blood cells

❑Both oxyHb (Hb02) and reduced Hb (Hb) are weak acids because their isoelectric points are less than the pH inside the red blood cells, which is 7.3 (refer to blood).

❑Accordingly, they combine with K+ (the main base present inside the red cells), forming KHbO2 and KHb. However, *Hb02 is more acidic,* so it combines with more K+ .

❑Therefore, in the tissues when Hb02 delivers 02 and becomes reduced Hb, some K+ is released as follows:

$$KHbO_2 \text{ (K-oxyhemoglobinate)} \rightarrow KHb \text{ (K-hemoglobinate)} + O_2 + \text{some } \underline{K^+}$$

***Some K is also liberated as a result of H+ buffering

Buffering (fate) of H+ in the plasma and red blood cells

- The released H+ after dissociation of H2C03 is buffered in the plasma by the plasma proteins and in the red blood cells by Hb. Reduced Hb is a stronger H+ acceptor than oxyHb, and when it buffers H+, K is liberated as follows:

$$H^+ + KHb \rightarrow H.Hb \text{ (hemoglobinic acid)} + \underline{K}^+$$

- H.Hb is a very weak acid that minimally disturbs the pH

Role of the plasma and red blood cells in tidal CO2 carriage

1. Role of the plasma: This carries about 10 % of the tidal C02 (5 % dissolved and 5% as HC03-, and a very small amount as carbamino compounds).

2. Role of the red blood cells: These carry about 90% of the tidal C02 (5% dissolved, 25% as *carbHb* and 60% as HCO3)

Consequences of addition of the tidal C02

1. The dissolved amount of C02 increases, so the Pco2 in the venous blood increases to 46 mmHg

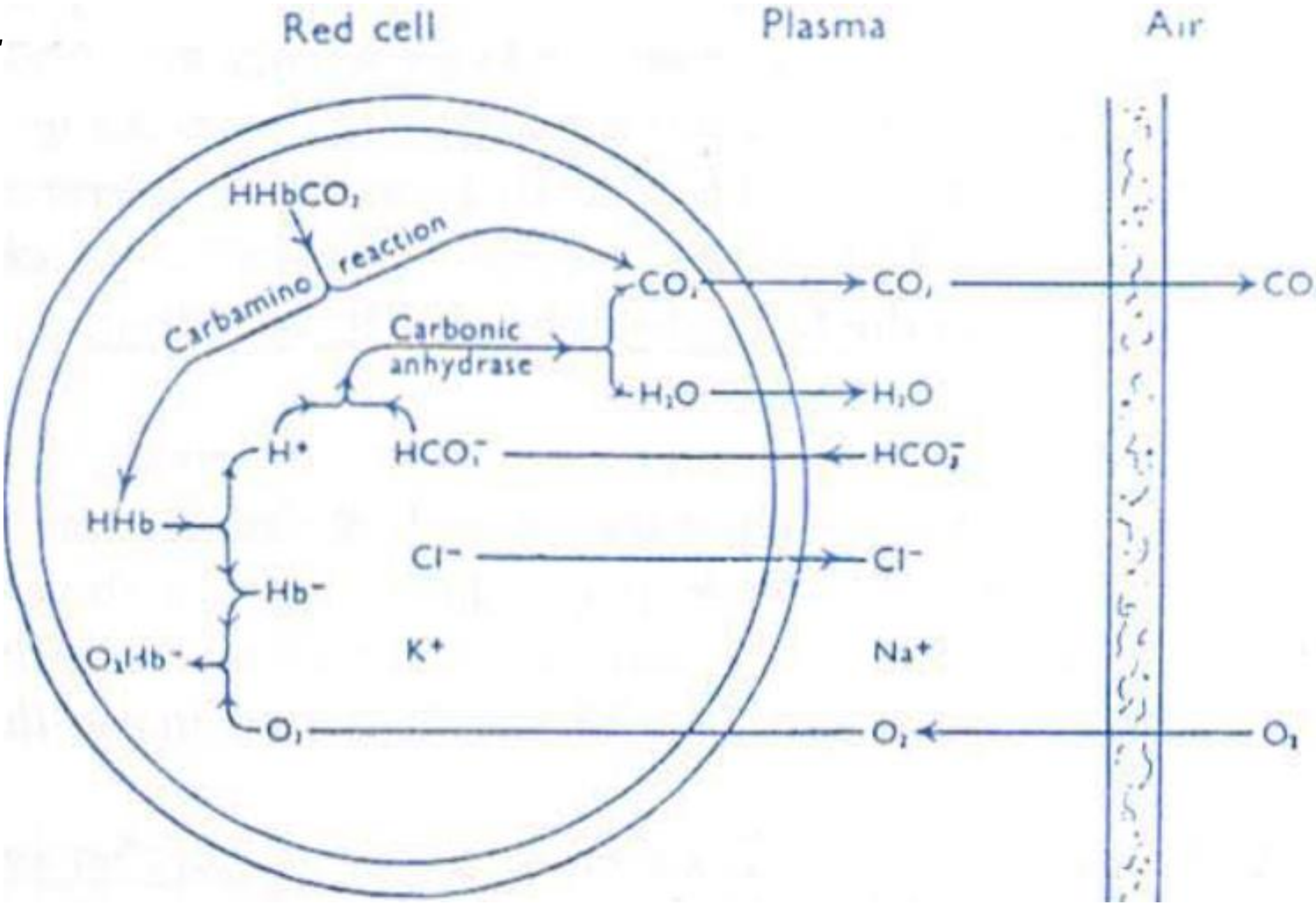
2. The carbamino compounds are increased (specially carbHb).

3. HC03- increases in both the red blood cells and the plasma.

4. Cl- increases in the red blood cells and decreases in the plasma.

5. The tonicity inside the red blood cells increases due to the increase in both HC03- and Cl- This withdraws water from the plasma by *osmosis* (= water shift). Consequently, the *volume of the red blood cells and the haematocrit value increase slightly in the venous blood*.

6. The formed H+ is efficiently buffered, so the blood pH drops only slightly (from *7.4 in the arterial blood lo* 7*.36 in the venous blood).*



Tidal CO_2 excretion in the lungs. Notice reversal of the Cl^- shift.

TIDAL C02 EXCRETION IN THE LUNGS

❑When the venous blood reaches the lungs in the pulmonary artery (in which the PCO2 is 46 mmHg), it is exposed to the alveolar air in which the *PC02* is lower (40 mmHg).

❑Accordingly, the excess physically dissolved C02 diffuses passively from the venous blood to the alveolar air under a *pressure gradient of 6 mmHg. The excess C02 in the carbamino compounds is also dissociated and excreted 111 the alveolar air*

- Also H^+ is released from HHb and binds to HCO3 that is obtained from KHCO3, forming H2C03. The *carbonic anhydrase enzyme* then catalyzes dissociation of H2C03 into water and CO2 which is excreted in the alveolar air.

- As a result, the HC03- concentration in the red blood cells decreases, so HCO3 diffuse from the plasma into the red blood cells while Cl- diffuse from the red blood cells to the plasma to maintain electric neutrality, and this is sometimes called reversal of the chloride shift

*** H^+ is released from H.Hb due to 02 diffusion from the alveoli and formation of Hb02, which is *a weaker H^+ acceptor than reduced Hb*.Hb02 then combines with the released K- from KHC03 and forms KHb02.

***About *200 ml CO_2 are normally excreted per minute during rest* because each I00 ml blood supply 3.7 ml *C02* , and the pulmonary blood flow (= cardiac output of the right ventricle) is about 5.5 litres / minute.

THE CHLORIDE SHIFT

- This is a phenomenon that occurs *while blood flows at the tissues.* The tidal C02 diffuses inside the red blood cells where it is mostly converted into HC03- by activity of the *carbonic anhydrase enzyme.*

- About 70% of HCO3- then diffuse outwards into the plasma, and in exchange, Cl- diffuse from the plasma into the red blood cells *to maintain electric neutrality.*

This process is completed in about 1 second, and is called the chloride shift. It results in the following changes in the blood :

1. The HCO_3 concentration increases in both the red cells and the plasma.

*2. T*he Cl^- concentration increases in the red cells & decreases in the plasma

3. The tonicity inside the red cells increases due to accumulation of both Cl^- and HCO_3^-. This leads to water movement from the plasma into the red cells by *osmosis(= water shift),* which results in *swelling of the red cells.*

***The **haematocrit value is normally about 3 % higher in the venous blood than in the arterial blood** because of

(a) The increase in the red cell volume as a result of water shift
(b) The return of some tissue fluid to the circulation via the lymph vessels (which concentrates the venous blood)..

*** Reversal of the chloride shift occurs in the lungs