Phosphate boosting may delay blackout during apnea through increased levels of 2.3DPG in the erythrocytes

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↑Phosphate boosting → ↑2,3DPG ?

Hemoglobine (Hb) consists of 4 polypeptide chains (amino acid chains). When fully oxygenated, Hb binds 4 oxygen molecules. As the blood circulates and the surrounding oxygen pressure (PO_2) drops, the Hb let go of one oxygen molecule. When this happen, the conformation of the Hb changes due to the interaction between the 4 polypeptide chains which leads to an even easier release of the next oxygen molecule. This property contributes to the so called sigmoid dissociation curve (S-shaped) Fig. 1. The dissociation curve of myoglobine is linear since it just consists of one polypeptide chain and binds one oxygen molecule. Depending on several parameters, it is possible to adjust the dissociation curve either to the right or left. At the end of an apnea, we want the curve to be adjusted as long as possible to the right. This means that the affinity of O_2 to Hb is lower than it would be if the curve was adjusted to the left. The 4 parameters that influence the dissociations curve are PCO_2, pH, 2.3DPG and temperature. Higher temperature lowers the affinity because the polypeptide chains are moving faster in relation to each other and therefore have problems to hold on to the O_2. CO_2 binds directly to the four N-terminals of the Hb and also lowers the affinity to O_2. CO_2 is also transformed by carbonic anhydrase to carbonate ions (CO_3^-) which is dissolved in the blood.

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

This leads to the production of hydrogen ions (H^+) which contributes to the decreased pH. Lower pH adjusts the dissociation curve to the right. As all freedivers know, hyperventilation contribute to a higher pH which not only lead to a later onset of the urge to breath, but also leads to the adjustment of the curve to the left which makes the Hb to hold on to the O_2 in a greater manner.

The interesting thing which I learned when I studied biochemistry was that there is one more parameter influencing the dissociation curve. That is the molecule 2,3 diphosphoglycerate (DPG), sometimes called 2,3 bisphosphoglycerate (BPG) which is a product in the glycolysis of the red blood cells (RBCs). DPG binds to and stabilize the tense-form of Hb which makes it more readily releasing O_2. One could think that this could influence the oxygenation of the Hb in the lungs negatively. However, due to the sigmoid pattern of the dissociation curve, this is not a big problem. So what is the determining factor to influence DPG? Interestingly, the first thing that happens when you are travelling to a high altitude is an increase in the DPG in the RBCs, The erythropoesis starts later. This increase of DPG happens due to the high pH as a cause of the increased breathing rate. The high pH activates an enzyme (phosphofructokinase) in the RBCs which increase the synthesis of DPG (1). This is actually pretty good because the oxygenation of the tissues would be impaired otherwise due to the higher affinity between Hb and O_2 caused by the increased breathing rate. In conclusion, ↑CO_2, ↑DPG and ↓pH is favourable at the end of an apnea for a sustainable oxygenation of the tissues. (High temperature is not favourable due to the increased metabolism). Exaggerated ventilation leads to an increased pH in the blood, makes the affinity going up which may lead to an earlier blackout. However, increased ventilation also leads to a higher saturation of the blood and has also been shown to increase the saturation of the venous blood. There are several causes to the higher saturation observed in the venous blood during ventilation. For instance, you get a higher pulse during ventilation which makes the heart/min volume going up. However, it may also be a cause of the higher pH as a result of the ventilation which make a higher proportion of the oxygen stay in the blood. (my own reflections).

Interestingly, several studies have shown that phosphate boosting may increase the levels of DPG in the RBCs (2-4). Several studies have also shown that boosting with phosphate increase the oxygen uptake capacity and performance (3;5-8). All the studies which showed positive effects used sodium phosphate. No effect was observed when boosting with calcium phosphate.
Hypothetically, this could lead to a delayed blackout to the freediver due to the lower affinity between Hb and oxygen. One study also showed that 6 days of boosting with phosphate increased the levels of Hb, however the mechanisms to this was unclear (5).

Dosage
The dosage used in the studies was ~ 1g sodium phosphate four times a day during 3 to 6 days in front of a performance.

Warning
Continuously intake of phosphate may be harmful due to the induced secretion of parathormone which may promote an excessive release of calcium from the bones. Further, increased intake of phosphate decreases the levels of 1,25$(OH)_2D_3$ (active vitamin D) which contributes to a decreased absorption of calcium in the intestine.
Other effects observed due to this hormone is the induction of the renal secretion of phosphate. As you understand, this contributes to a limited effect when administered during a longer period.

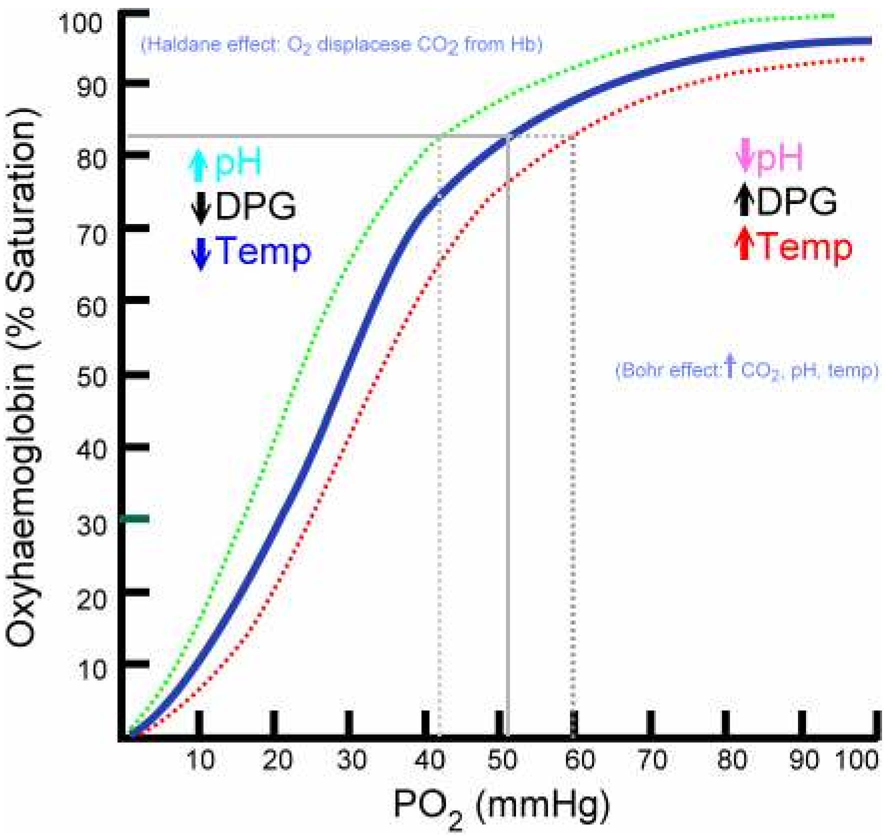
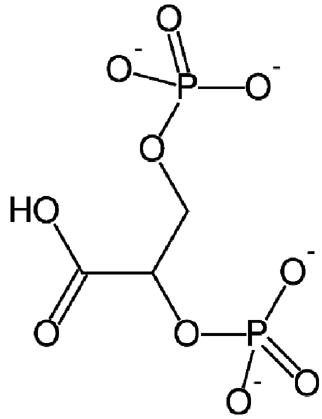


Fig.1. The sigmoid dissociation curve of hemoglobine



2,3DPG

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