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Hemoglobin- Revisited

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Abstract

Hemoglobin is described as the hydrogen atom of molecular biology by Jeffery Wyman thirty years ago (Wyman, 1964) and is one of the first few proteins to be crystallized and structure elucidated. A wealth of experimental data including structure function relationship is available on hemoglobin (Perutz et al., 1987). The renewed interest in this ancient protein is due to its importance in the development of artificial blood substitutes and its implication to protein evolution. This article focuses on crocodile hemoglobin, which has unique oxygen binding property. Purification, crystallisation and modelling studies have been carried out on crocodile hemoglobin.

Introduction

Crocodiles remain underwater for considerable period of time without surfacing to breathe and often kill their prey by drowning. This is due to the fact that the bicarbonate ions, which are the end product of respiration, drastically reduce the oxygen binding affinity of crocodile hemoglobin leading to the release of bound oxygen to the respiring tissue (Komiyama et al., 1995). On the other hand, the diving capabilities of whales and dolphins, is derived from the stored oxygen in their muscle myoglobin. Thus crocodiles can utilize almost 100% of the oxygen in their blood while human beings can only use about 65% of it. The physiological role of bicarbonate ion binding in crocodile hemoglobin is two folds. First it helps in the tapping of stored pulmonary oxygen during dives as a significant increase in oxygen affinity of hemoglobin occurs when CO₂ is

given off from the blood to lungs. Secondly, the release of bound oxygen from the blood to tissues at relatively high partial pressures of oxygen.

Structural studies on crocodile hemoglobin Crocodile and man diverged 300 million years ago and only 68% of their alpha chain and 51% of their beta chain are homologous. There are number of effector molecules such as H^+ , CO_2 , Cl^- and Diphosphoglycerate which can alter the oxygen affinity of hemoglobin of most species. In these cases oxygen can be delivered with great efficiency, when required, by increasing the concentration of effector molecules. Crocodile hemoglobin (CroHb) is rather unusual in the sense that it does not respond to any of the effector molecules mentioned above but responds strongly to bicarbonate ions. The loss of allosteric inhibition by the effector molecules is attributed to a few key substitutions in the primary sequence, five in the beta chain and seven in the alpha chain (Perutz et al., 1981). This finding suggests that the adaptation to new environment can be achieved by a relatively small number of substitutions in key positions.

In order to understand this phenomenon we have carried out structure prediction and modeling studies on CroHb. Human deoxy hemoglobin sequence gave a high score when compared with Nile crocodile amino acid sequence using prediction algorithms like SOPMA and BLAST. Key amino acid residues were replaced from this structure to mimic

CroHb and were used for modeling. The docking of bicarbonate ion with this model using BIOSYM software shows that Tyr42 α 1, Asp99 β 2, Tyr41 β 2 are involved in hydrogen bonding with bicarbonate ion. Interestingly excepting Tyr41 β 2, which is unique to CroHb, the other two residues are conserved between human and crocodile. This suggests that the 12 amino acid substitutions implicated in the bicarbonate effect may perturb the structure to create the binding site for bicarbonate binding rather than directly participating in the process.

We have isolated, purified and crystallized hemoglobin from salt-water crocodile (*C. Porosus*) blood to verify the above theory using X-ray diffraction. (Rajesh, Kamalakannan & Vasantha Pattabhi, 1998). The purified sample polymerizes on storage for few days, which is similar to the polymerization of hemoglobin of several species

(Reischl & Diefenbach, 1976) in vertebrate taxa including Chelonia (turtle) and squamata (lizard). The electrophoresis of the aged hemoglobin on a native poly acrylamide gel exhibit extensive trailing and is attributed to disulfide bond formation, which is obvious from the fact that the polymerization can be reversed by addition of N-ethyl maleimide.

Designing artificial blood substitutes

There is an urgent need to engineer artificial blood substitutes due to the increasing concern over blood transmitted viral and bacterial pathogens. Several attempts have been made in this direction. Cell free hemoglobin solution and human hemoglobin synthesized in E.Coli have been investigated as potential oxygen carriers. But these can not be used as blood substitutes as in these cases the oxygen affinity in the absence of allosteric modulators is very high to allow any unloading to tissues. Secondly the hemoglobin tetramers dissociate in to dimers which will be cleared by the kidneys causing renal damage in the long run. In view of these, hemoglobin hybrids like human α -crocodile β (Hb Scuba) and vice versa are being engineered to be used as blood substitutes (Brunori, Cutruzzola & Vallone, 1995). Since the oxygen affinity of crocodilian hemoglobin is affected only by CO₂ (which dissolves in to plasma as bicarbonate ions), oxygen can be unloaded in to respiring tissues which release CO₂. Our ultimate aim is to design such blood substitutes using structural information.

References

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