DEEP DIVING
How Do They Do It?

The elephant seal is a truly champion diver, going to depths as great as 5788 feet, staying under for periods up to two hours and diving repeatedly over periods of months with only brief breathing periods on the surface. This article will look at the many elements that make that possible.

The first, common to all mammals is the **dive response**. When the seal's head is immersed four things happen: breathing stops (apnea), pulse rate drops, arteries and veins in extremities are reduced in diameter and blood is pushed into the lungs. In elephant seals the drop in pulse rate can be dramatic – drops by factors of eight to ten. The blood pressure remains fairly constant, maintaining the rate of flow to the brain and heart. The pulse rate appears to be subject to some control as it drops less in advance of short dives and more for longer dives.

The oxygen supply in elephant seals at the beginning of a dive is considerable. On diving, the seal exhales so that little air is left in the lungs, accounting for less than 5% of the oxygen supply. While that oxygen is used in the early moments of the dive, as the depth and pressure increase, the lungs completely collapse forcing the remaining air into the trachea. Elephant seals are 22% blood by weight, compared to 7% for humans. Their blood is richer with over 60% of blood volume occupied by red blood cells compared to 40% - 45% for humans. In addition to the blood oxygen, held by hemoglobin molecules in the red blood cells, there is oxygen in the muscle held by myoglobin molecules. Per pound of body weight the elephant seal has more than 15 times as much myoglobin as a human.

While the structure and size of an elephant seal heart is similar to that of a land mammal, there are important differences in the circulatory system. The arterial system is, for the most part, similar to that for humans. Differences include an elastic enlargement of the aorta which may help to keep the blood flowing throughout the heart cycle. In addition there are elaborate networks of arteries and veins that contribute to blood capacity. These networks can also provide for heat exchange, for example between the warm arterial blood heading for the rear flippers and the cold venous blood returning from those flippers.

The system of veins has some features that are common to most seals but not found in land mammals.

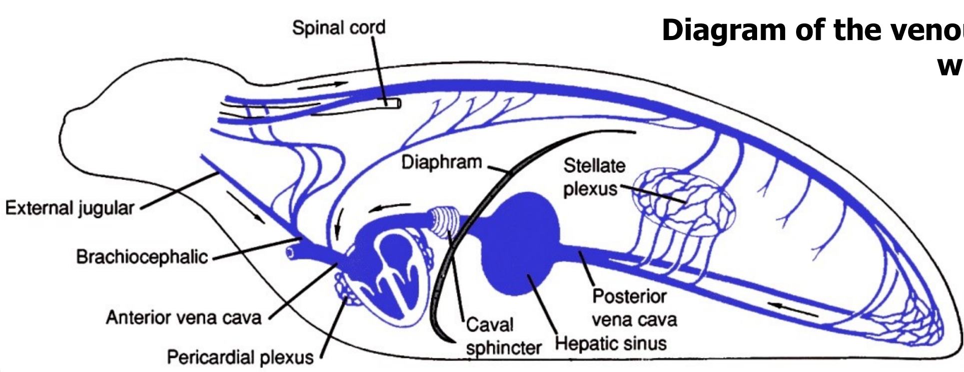


Diagram of the venous circulation in a phocid with major vessels labeled
(*Seals of the World*, J. E. King, 1983)

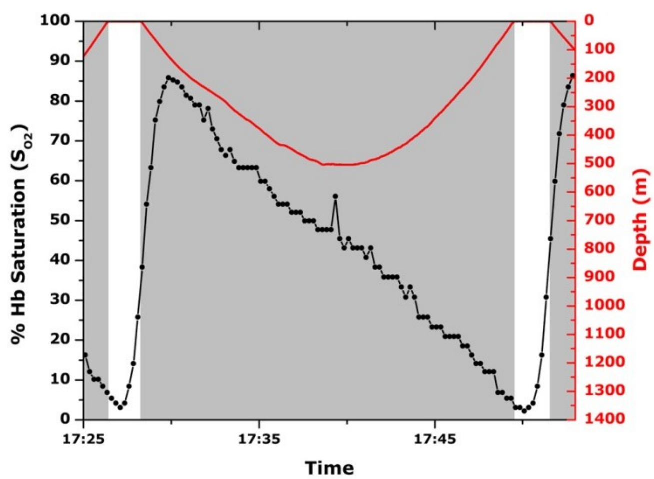
Not shown is the spleen, located just below the hepatic sinus. The spleen is large in phocids such as the elephant seal – about 4.5% of body weight – and is capable of holding oxygenated red blood cells and, triggered by apnea, injecting them into the sinus. While the injection is fast, the recharge of the spleen takes a long time so on a typical ocean voyage by an elephant seal with the 2.5 minute breathing periods the spleen is likely not a contributor to diving ability. It may serve during apnea on the beach where the breathing times are longer.

Some of the networks (plexi) are shown. The large and elastic posterior vena cava and hepatic sinus absorb the blood from the extremities during the dive response. The rate of blood return to the heart is regulated by a sphincter muscle, the caval sphincter.

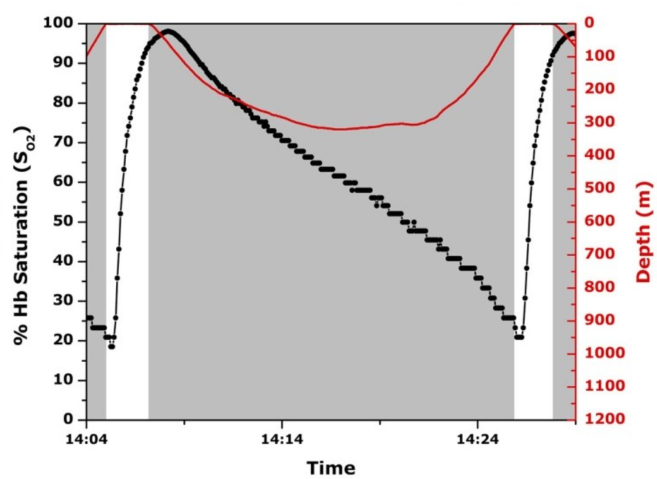
A fourth factor is size. The larger the animal the less oxygen per unit mass is necessary for its activities.

Finally, the secret to the elephant seals ability to dive continuously for extended periods is its ability to function aerobically on very low blood oxygen levels, showing an extraordinary tolerance of low oxygen and management of blood stores. A recent study[1] of blood oxygen levels in elephant seals at sea has shown that for dives longer that ten minutes, the great majority of dives, the blood oxygen concentration drops to a far lower percentage than is found in or survivable by other mammals. The profile of oxygen saturation during a diving bout is shown below. The study did not include an analysis of myoglobin stores through the dives. While lactic acid producing anaerobic (oxygen-less) processes are possible, they cannot be significant for constant diving with brief breathing periods since clearing the blood of lactic acid is too time consuming. The charts show the saturation level of the blood through a dive sequence, the depth is shown in red, the degree of saturation in black. The period when the seal is at the surface is white. Note that the oxygen saturation begins to rise in the artery shortly after surfacing, while that in the hepatic sinus takes about a minute longer. These are from different animals but the data from those locations are representative.

Oxygen Saturation in Hepatic Sinus



Oxygen Saturation in an Artery



Percentage of blood oxygen saturation through a dive as measured in the hepatic sinus and an artery Dive depth in red, saturation in black.

[1]Meir, J. U., *et al.*, Extreme hypoxemic tolerance and blood oxygen depletion in diving elephant seals, *Am J Physiol Regul Integr Comp Physiol* 297: R927-R939, 2009

Compiled by Brandt Kehoe 5/2015