ON THE RESPIRATORY FUNCTION OF THE BLOOD OF THE SEA LION

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The capture of a Steller's sea lion, *Eumetopias stelleri,* at the Hopkins Marine Station has afforded an opportunity to obtain certain data on the conditions of equilibrium between the blood of an aquatic mammal and the respiratory gases, which have not been available before. The animal, which proved to be an old female, was blind, and having been wounded with a rifle shot while it sat on the rocks in front of the station, was secured with a gaff as it attempted to escape and brought to shore. There it was killed by severing the great vessels in the neck and a sample of 200 cc. of blood was collected as it flowed from the wound. The animal was somewhat emaciated, but was not in a starving condition as evidenced by a quantity of fish in its stomach and the abundance of fat in the lacteals. The bullet wounds were found to be limited to bony and muscular structures and had not caused extensive bleeding. We are indebted to Dr. G. E. MacGinitie for placing the blood at our disposal.

The blood was prevented from clotting by the addition of potassium oxalate; and was kept on ice during the subsequent sixteen hours in which measurements were made. Samples were equilibrated with various gas mixtures in a water bath at 38° C. for 20 minutes and then analyzed for oxygen or carbon dioxide with the Van Slyke "constant volume" apparatus. The gas mixtures were subsequently analyzed with the Haldane gas analysis apparatus. The resulting data are recorded in Tables I and II. In order to correct the observed oxygen contents for the dissolved oxygen, an absorption coefficient of $\alpha = 0.022$ was assumed. The volume of erythrocytes in the blood was determined with the centrifuge and proved to be 29 per cent of the total volume of the blood.

Since all the observations recorded above were made in a short period of time upon a single sample of blood, there was no opportunity

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to check the results, which must in consequence be regarded as provisional.

TABLE I

Data on the equilibrium of sea lion's blood with oxygen. Temperature 38° C.

Carbon dioxide pressure	Oxygen pressure	Oxygen content	Oxygen dissolved	Oxygen as oxyhemoglobin	Saturation
mm. Hg	*mm. Hg*	*vol. per cent*	*vol. per cent*	*vol. per cent*	*per cent*
42.20	27.53	5.23	0.08	5.15	25.9
42.80	32.00	6.75	0.09	6.66	33.5
47.00	43.00	10.95	0.12	10.83	54.5
26.20	14.32	2.12	0.04	2.08	10.5
21.20	34.55	10.70	0.10	10.60	53.4
24.20	27.55	12.75	0.08	12.67	64.8
24.30	33.30	11.56	0.10	11.46	57.7
106.50	61.55	11.67	0.18	11.49	58.0
air	air	20.40	0.45	19.95	100.5
air	air	20.21	0.45	19.76	99.5

TABLE II

Data on the equilibrium of sea lion's blood with carbon dioxide. Temperature 38° C.

	Oxygen pressure	Carbon dioxide pressure	Carbon dioxide content
	mm. Hg	*vol. per cent*	*vol. per cent*
Oxygenated	150 ca.	45.60	39.15
	150 ca.	14.45	22.45
	150 ca.	46.40	38.01
Reduced	8.20	54.90	46.00
	4.20	45.20	43.20

DISCUSSION OF RESULTS

In the blood of an aquatic mammal it is reasonable to look for conditions which favor the circulation of oxygen to the muscles in order to maintain the great energy expenditure required for rapid progression through a viscous medium. One may also anticipate an increased oxygen capacity to enable the animal to remain longer under water. In the present instance the oxygen content of the blood when equilibrated with air was 19.8 volumes per 100 volumes of blood. This was not a greater oxygen capacity than commonly occurs in man and other mammals. The volume occupied by the erythrocytes was only 29 per cent of the total blood, a figure much less than that commonly

found in active terrestrial mammals. Each cubic centimeter of corpuscles combined with 0.68 cc. oxygen. Drastich (1928) has found that in a large number of domestic mammals the concentration of hemoglobin in the erythrocytes is approximately the same, being about 32 grams hemoglobin per 100 cc. blood corpuscles. Taking one gram of hemoglobin to combine with 1.34 cc. oxygen, each volume of corpuscles combines with 0.43 cc. oxygen. It appears then that the sea lion corpuscles combine with about one and one-half times as much oxygen as do those of the domestic mammals, *i.e.,* the hemoglobin is just that much more concentrated within them. We suspect that the blood under examination may represent a somewhat anaemic condition and that the blood of a younger and more vigorous sea lion would exhibit a higher cell volume and oxygen capacity. Whether or not that is the case, there can be little doubt that the unusual concentration of hemoglobin in the

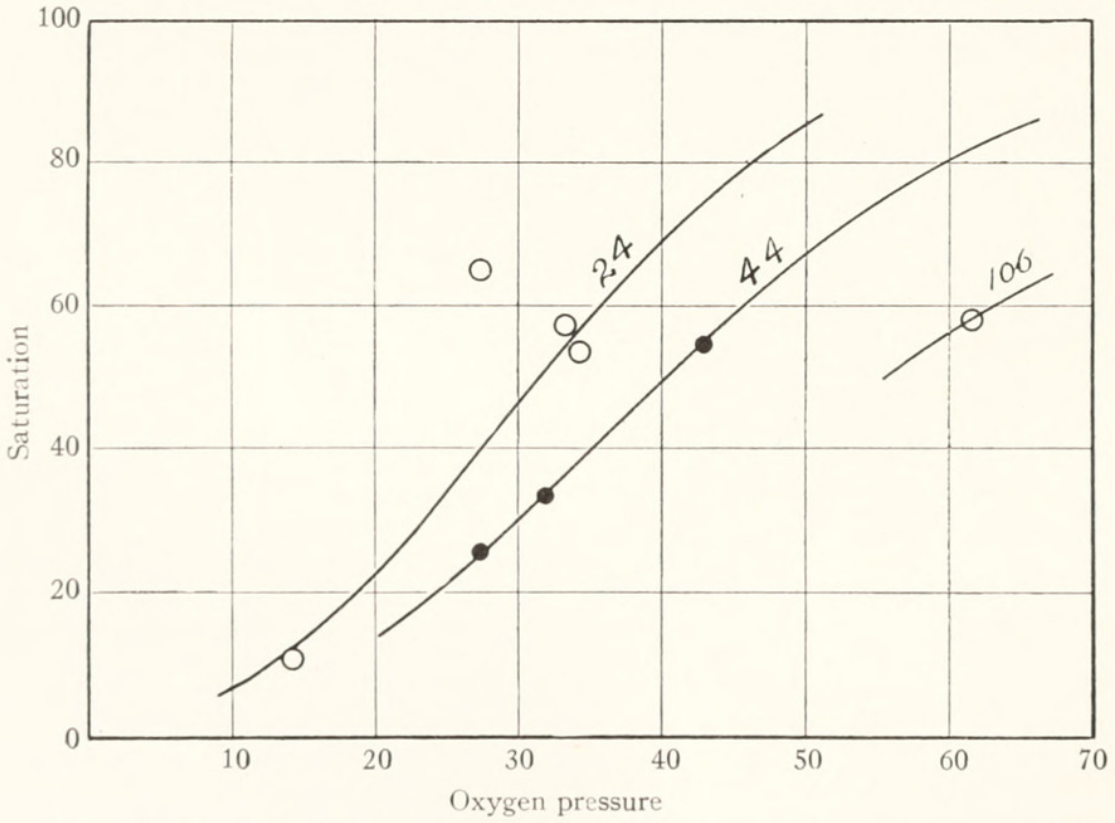

FIG. 1. Oxygen dissociation curves of blood of sea lion at 38° C. The approximate pressures of CO_2, in mm. Hg, at which the blood was equilibrated are indicated by the numbers above the curves. Ordinate, percentage of saturation with oxygen; abscissa, oxygen pressure in mm. Hg.

corpuscles of this specimen represents an advantageous condition in that it minimizes the work which must be done by the heart in circulating oxygen through the muscles.

Sudzuki (1924) reports in the case of porpoise blood (Tümmler-

blut) oxygen capacities of 42.5 and 45.1 volumes per cent. The erythrocyte count in the animals studied varied between 8.4 and 11.2 million per cubic millimeter. Since the erythrocytes of the Cetacea are slightly larger than those of man (Marimoto, Takata, and Sudzuki, 1921), it would appear that in the porpoise the increased oxygen-carrying power is accomplished by increasing the number of blood corpuscles rather than by augmenting the concentration of hemoglobin within the corpuscles.

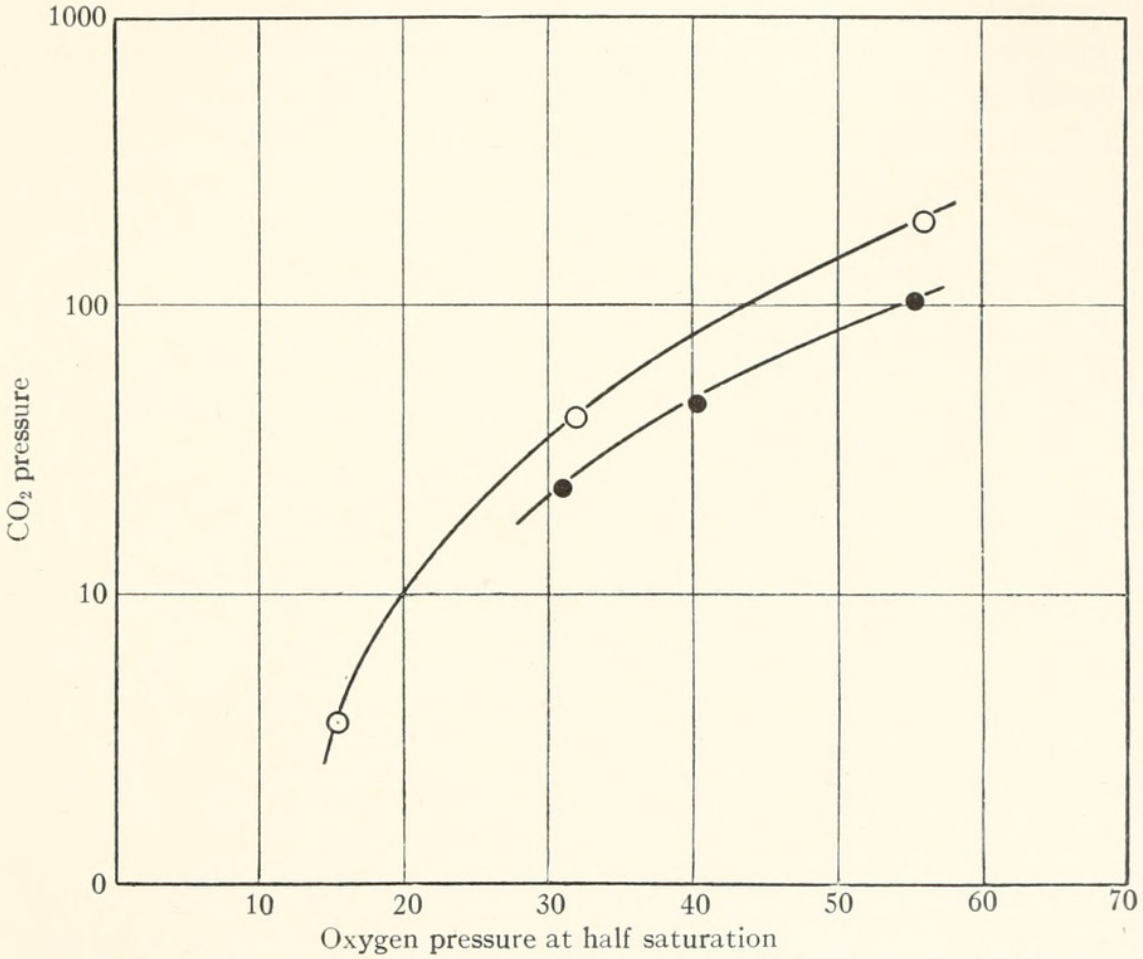

FIG. 2. Oxygen pressures at which the blood of the dog, upper curve, and of the sea lion, lower curve, are half saturated with oxygen in the presence of varying quantities of CO_2. Ordinate, pressures of CO_2 in mm. Hg plotted on a logarithmic scale; abscissa, oxygen pressure in mm. Hg at half saturation.

THE OXYGEN DISSOCIATION CURVE

In Fig. 1 curves are presented which indicate the general nature of the equilibrium of sea lion blood with oxygen at various carbon dioxide pressures. The general form and distribution of the curves resembles that of the blood of other mammals. In order to compare equilibrium conditions in the case of the sea lion with those characterizing the blood of the dog, the pressures of oxygen at which the hemoglobin is half saturated have been plotted in Fig. 2 against the corresponding carbon

dioxide pressures. Similarly, a curve has been drawn representing this relation in the case of the dog's blood from data kindly supplied by Dr. D. B. Dill. It appears that oxygen is held at somewhat higher tensions in the blood of the sea lion than in that of the dog. The difference between the two species is not greater than that exhibited by various specimens of human blood, however. The advantage of this difference, in so far as it exists, in facilitating the rapid diffusion of oxygen into the active muscle fibers, is obvious. The slope of the curves also indicates that a given change in CO_2 tension will cause a greater change in oxygen tension in the case of the sea lion,—again a condition favoring the respiratory exchange.

The Carbon Dioxide Equilibrium

The data in Table II serve to demonstrate the essential facts regarding the equilibrium of carbon dioxide with the blood. If the data are plotted, it will be found that the usual type of CO_2 dissociation curve can be drawn through the points. The carbon dioxide combined at any pressure is somewhat less than in the case of dogs studied in Dr. Dill's laboratory. This condition may very probably be due to the presence of lactic acid in the blood resulting from the struggles of the sea lion in the course of its capture.

The difference in CO_2 content of oxygenated and reduced blood is similar to that of the blood of other mammals.

Summary

The blood of a sea lion, *Eumetopias stelleri,* was found to have an oxygen capacity of 19.8 volumes per cent.

The erythrocytes composed 29 per cent of its volume.

One volume of erythrocytes combined with 0.68 cc. oxygen, indicating a hemoglobin concentration 50 per cent greater than that found in domestic mammals.

The oxygen dissociation curves constructed at various pressures conform to the usual mammalian type, but indicate that oxygen may be held at slightly higher pressures than in the case of dog blood.

The carbon dioxide equilibrium is in no way remarkable and exhibits the usual difference between oxygenated and reduced blood.

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