THE RELATION BETWEEN THE SIZE OF THE HEART AND THE OXYGEN CONTENT OF THE ARTERIAL BLOOD. BY K. TAKEUCHI.

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THE object of the following research was to correlate the degree of dilatation of the heart with the oxygen content of the arterial blood. It is, of course, currently known that a sufficient degree of anoxœmia produces cardiac dilatation, yet out of five subjects (1) who were investigated at an altitude of over 14,000 feet in Peru, and who undoubtedly had an abnormally low oxygen content in the arterial blood, none showed any sign of a larger X-ray heart shadow whilst in three cases the shadow was actually smaller than at the sea level. There seemed to be two possible explanations of the fact that the heart in these cases did not dilate, (1) that the degree of anoxœmia was insufficient, (2) that acclimatisation to the anoxœmia had taken place. I have, then, investigated the immediate effect of anoxœmia and whether some critical degree of anoxœmia is required before dilatation of the heart takes place. The experiments were made on cats anæsthetised with urethane and C.E.

At first some crude experiments were made in which the chest was opened and the heart viewed through a glass plate. The general impression of the size of the heart could be sketched on the plate with a grease pencil and even this simple and inaccurate process left no doubt that when the oxygen in the air breathed by the cat was reduced the area traced on the glass immediately became larger. This method was unsatisfactory because (among other reasons) it gave no information as to whether the alteration of the size of the heart was principally an alteration in the systolic or in the diastolic size, and, indeed, X-ray photos are none too definite on this point. Prof. Langley suggested that we should use the cinematograph and after a number of preliminary experiments, three were obtained which are worth recording.

The general plan of these experiments was that the chest was opened, artificial respiration maintained, and the inspired air varied in composition. A preliminary investigation of the conditions obtaining in the open chest, when the animal was under artificial respiration, was undertaken. A description of the apparatus ultimately used and a statement of its efficiency are recorded in another page (2).

The experiment was divided into four or five periods, the composition of the inspired air being gradually changed. In the first period a mixture of oxygen and atmospheric air was given; in the second, air; in the third, a mixture of air and nitrogen, and in the fourth a mixture richer in nitrogen than the third. During each period a short film was taken. The pressure of inspired air and the rate of rotation of the motor of the artificial apparatus were kept constant so that the respiratory conditions, other than the composition of the air remained constant. The CO_2 was therefore removed at the same rate as in an experiment in which air was breathed the whole time. The programme for a single experiment was as follows.

Two samples of each of expired and inspired air were collected in a football bag and Barcroft's tonometer respectively at each period of the experiment; O_2 and CO_2 in the samples were measured by Haldane's apparatus and the total volume of expired air per min. was measured by gas meter. Two samples of arterial blood were taken from the carotid artery at each period and the percentage saturation of oxygen was measured by Barcroft's differential manometer. All the samples and the photographs were taken as nearly as possible at the same time so as to get simultaneous results. The cinematograph photographs taken of the heart beating at each period, were enlarged and measured in length, width and area of hearts.

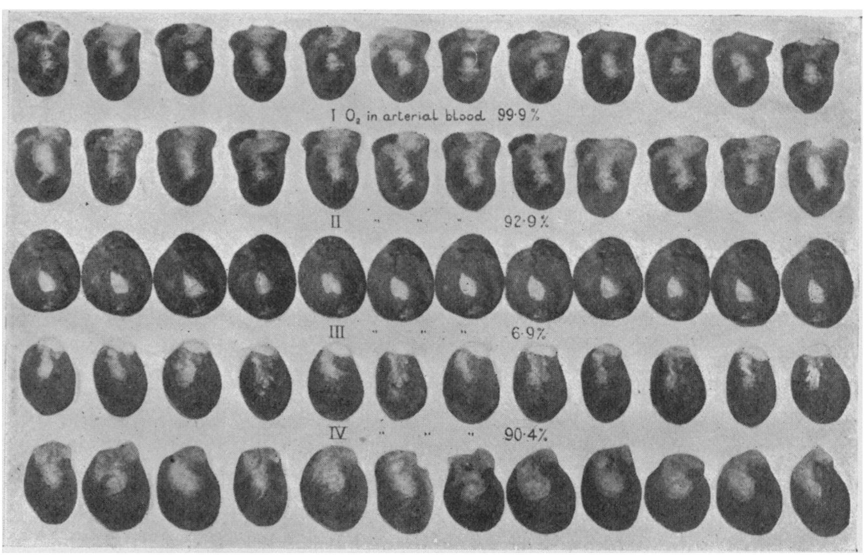

Fig. 1.

To obtain a record of the horizontal projection of the area prints were taken of the films. The photographs of the heart were cut out and traced on to millimetre squared paper. The number of square millimetres which the figure covered was then counted.

Three such experiments were performed. Fig. 1, which reads horizontally, shows a typical record of the successive photos cut out from five strips of film; each strip corresponds to one period of the experiment, the first period being at the top. The following are the data:

Exp. 3. Cat under urethane.

	Time	
	0 m.	Start operation.
1 h.	12	Finish operation.
,,	24	Period I commences (oxygen).
,,	29–35	Samples of inspired and expired air taken.
,,	36	Arterial blood.
,,	38	Film I.
,,	45	Period II commences (air).
,,	48–52	Samples of expired and inspired air.
,,	53	Samples of arterial blood.
2 h.	2	Film II.
,,	2½	Period III commences (nitrogen let into mixing bottle).
,,	4–5	Samples of inspired and expired air.
,,	4	Film III.
,,	9	Period IV, atmospheric air.
,,	11–15	Samples and inspired and expired air.
,,	15	Arterial blood.
,,	21	Period V, nitrogen.
,,	21	Film V.

Analyses.

Period	Inspired air p.c. of O_2	Expired air p.c. O_2	Expired air p.c. CO_2	Arterial blood p.c. sat. with O_2	Comparative area of heart
I	93	92	1·2	100	106– 94
II	21	19·5	1·2	93	111–106
III	15·5	13	7·9	7	164–152
IV	21	19·5	1·3	93	115–103
V	Low	—	—	Low	126–103

Each change in the composition of the air breathed produces an immediate alteration in the size of the heart. The rapidity of the response is a matter which is as remarkable as the degree. Thus, only 2 minutes elapsed between films II and III. Yet even without the aid of measurements the difference is obvious enough in the figure.

Further, the alteration appears to be reversible for in period IV the heart has reverted to the condition of period II. In the table of analyses the largest and smallest areas of the heart in each film are given and the two periods (IV and II) correspond very closely.

A third point to be observed is that there is a definite dilatation of the heart in period I as compared with period II.

Unfortunately it was impossible to get blood samples for period V which purports to be a repetition of period III. The film of period V is however worth reproducing, because as compared with that of period III, there is a much greater difference between systole and diastole. Possibly dilatation affects the diastole before the systole, but that is a matter for future investigation. The phenomenon is shown very clearly in Fig. 2

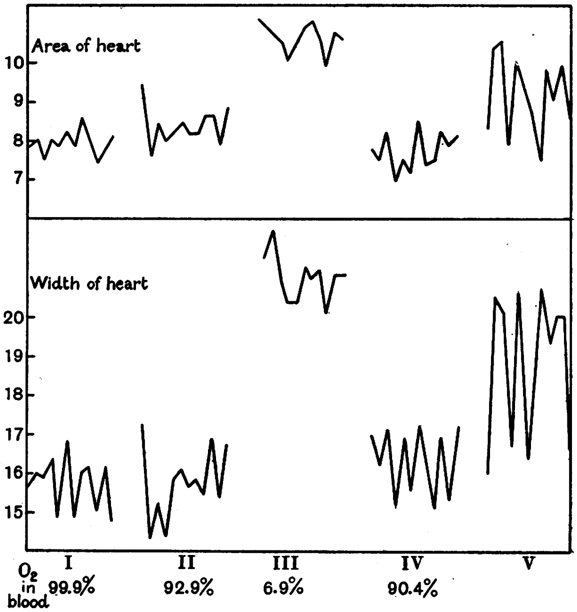

Fig. 2.

in which the dimensions of the heart are plotted in relative terms. It must not be supposed that the amplitude of the heart-beat is as irregular as the oscillation on the diagram. The figures represent really a series of interference observations affected equally by the frequency of the heart-beat and the frequency of the exposure of successive films, but it may be taken that the maximal and minimal measurements, approximately represent the diastole and systole respectively.

A comparison of the amplitudes for width and area in Fig. 2 show that the two vary in strict relationship to one another. The variations in the amplitude of the length are much more constant and also smaller.

Amplitude expressed as percentages of the minimum.

Period	I	II	III	IV	V
Area	15	24	15	19	32
Width	12	19	12	13	30
Length	7	6	7	5	8

But although the variations in length are rather constant for each heart-beat whether the heart be dilated or not, the length takes part in the general dilatation due to anoxœmia as may be seen from the figure. The length measurements are much more difficult to be certain about than those of the width.

In Exps. 1 and 2 the routine was a little different. Instead of an alternation between air and an oxygen-poor atmosphere with two periods of each (periods II–V), there was a gradual transition from oxygen to the atmosphere richest in nitrogen over the first four periods, whilst the fifth was air. The general result was quite in accordance with Exp. 3, there being only one apparent discrepancy, namely, that administration of air at the end of Exp. 1 did not reduce the heart. The reason was that the air came too late, the animal being by that time moribund and the air did not prevent its dying. Probably the circulation had almost ceased though the heart was just beating visibly when the air was given.

Fig. 3 represents a composite picture of the relation of the percentage

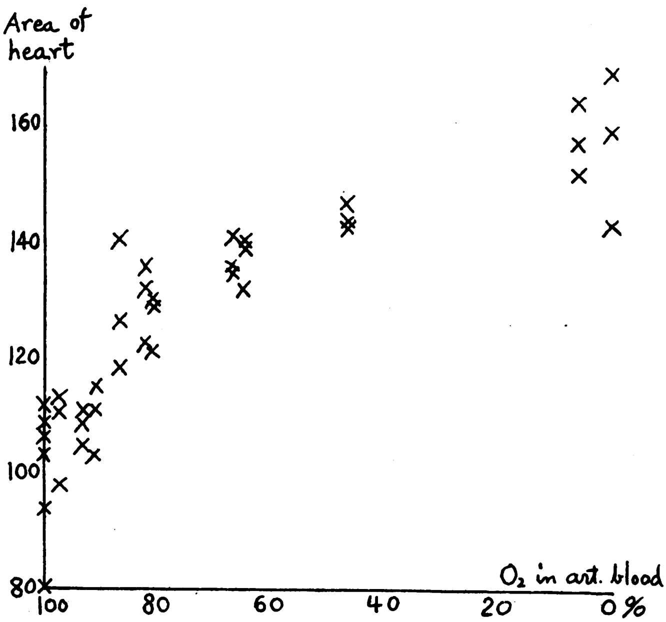

Fig. 3. Relation between area of heart and percentage saturation of oxygen in arterial blood.

saturation of the arterial blood to the limits of area of the heart shadow. It gives the definite impression that the most considerable changes in dilatation are in the earlier stages of anoxœmia. The average saturation of the blood of the person observed in Peru was about 85 p.c. and similar saturations have been observed by Adair and Gildea (1, p. 362) in the Rocky Mountains. The trend of the present research is to show that at 85 p.c. saturation the heart is considerably dilated.

Clearly results brought about by rapid changes in the cat cannot be compared unreservedly to alterations which are brought about by gradual changes in man. Apart from the difference of the species of animal used, the time factor must be considered and the suggestion is that when fit men live at high altitudes acclimatisation takes place. How far the acclimatisation lags after the dilatation we do not know, it may be that the acclimatisation can take place almost as fast as the person ascends, so that the dilatation is only potential, but the single observation made on this subject by the Peru party did seem to show that Meakin's heart became reduced in size between the time of his arrival at Oroya (12,000 feet) and that of his subsequent departure from Cerro (14,000 feet). Again, we have noted that in our experiments the reduction of the heart area on the transition from an oxygen poor atmosphere to air is immediate. It must not be supposed that the immediate administration of oxygen to a patient who has been subject to anoxic conditions will necessarily have the same effect. Somervell observed not only that on Mount Everest the cardiac dilatation was the rule, but that the dilatation did not go away for some time after the party came down, in fact till they reached Darjeeling. It would appear likely that the rapidity with which oxygen reduces a heart which has been dilated owing to anoxœmia, depends on the length of time over which it has been dilated. In these experiments the dilatation though extreme, was for only a few minutes and it was abolished immediately on giving oxygen. In the case of the Everest party, the dilatation lasted over weeks and took a correspondingly long time to pass off.

The work done by the heart. It scarcely needs pointing out that in the anoxœmic periods the heart is working much less economically than in the normal ones. In accordance with the views put forward with regard to striated muscle by A. V. Hill (3) and applied to the heart by Starling (4), the energy expended at each beat is a function of the length of the fibre. It has been shown by Doi, that in preparations such as we used the total output of blood per minute is not increased. It is not possible to make any calculation from the figures given above of the energy expended by the heart for a given output of blood. We know from the work of Doi that the output of blood will fall off; we have the pulse rates, and the maximal width or length in each period to give some idea of the degree of elongation of the fibres. Thus in Exp. 3.

Period	Breathing	Pulse rate	Relative width
II	Air	125	17
III	Nitrogen + air	105	22
IV	Air	125	17

From the above it appears that in this experiment the heart slows almost exactly in the same proportion as it dilates. If one regarded the potential energy liberated per minute as

$$\tfrac{1}{6}TLF,$$

where T is the maximal tension, L the length of the fibre in diastole, and F the pulse rate, and taking the change of diameter as a measure of L, LF remains nearly constant and the potential energy would vary roughly with the systolic pressure. Here, again, the conditions differ from those of a person at great heights when the pulse is dilated and *quickened* without apparently any increased output as the result.

SUMMARY.

1. The reduction of oxygen in the air breathed by a cat produces immediate enlargement of the heart. The re-administration produces immediate reduction.

2. The principal effect on the size of the heart seems to be in the less extreme ranges of anoxœmia, thus the alteration is much greater between 100 p.c. and 80 p.c. saturation of the arterial blood than between 40 p.c. and 20 p.c.

3. The greater elongation of the fibres means a greater output of energy at each beat, other things being equal.

4. The time relations given in this paper cannot be applied to conditions of anoxic anoxœmia of long duration without reference to the degree of compensation of the chronic changes set up in the heart.

REFERENCES.

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(3) Hill, A. V. Ibid. 46. p. 435. 1913.

(4) Patterson, Piper and Starling. Ibid. 48. p. 465. 1914.