GASEOUS EXCHANGE WHEN OXYGEN IS INHALED

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The problem as to how the gaseous exchange will alter when high concentrations of oxygen are inhaled originated immediately after oxygen had been discovered and the quantitative composition of the atmosphere determined.

The widespread use of oxygen in aviation and in medicine, both for treatment and prevention of anoxemia and as a general therapeutic measure, makes it important to study its effect on many physiological processes, and in particular on gaseous exchange.

However, there is considerable inconsistency in the results obtained by different workers. According to some [1,2,3], breathing almost pure oxygen does not affect the gaseous exchange, while others [4, 5, 6] claim that the gaseous exchange is reduced.

It must be noted that the great majority of workers consider that an increased barometric pressure depresses the oxidative processes only when the values are as high as 10-15 atmospheres.

The differences obtained when observing the effect of breathing oxygen on gaseous exchange and on the rate of oxidative processes are probably due to the fact that in different experiments the gas has been administered for different lengths of time, different amounts have been given, etc.

In the present work a study has been made of the gaseous exchange in animals breathing almost pure oxygen. It was measured in terms of the amount of carbon dioxide given out by the animal during a measured time.

METHOD

The experiments were carried out on 45 white rats. The method we used allowed us to study the gaseous exchange when breathing air with the normal oxygen content; the animal was then rapidly transferred into an atmosphere containing 93-95% oxygen, and, without interrupting the experiment, several determinations of the amounts of carbon dioxide given off at different times were made.

The animal was placed in small chamber through which air was sucked by a special pump; before entering the chamber, the air was made to pass through a washbottle containing alkali to remove the carbon dioxide.

The ventilation of the chamber was carried out so as to prevent any accumulation of carbon dioxide gas in it. The oxygen was supplied directly from an oxygen cylinder through a pressure-reducing valve, and the rate of flow was approximately the same as when normal air was used.

The percentage oxygen in the cylinder was determined by a gas analysis using Haldane's method. The carbon dioxide given out by the animal was absorbed in alkali placed in 2-3 washbottles through which the air or oxygen from the chamber was drawn, and it was measured by Winkler's method and referred to 100 g weight of the animal per hour.

Thus, our method enable variations in the rate of production of carbon dioxide to be studied, and made it possible to compare the amounts given out before, during, and after breathing pure oxygen, and to vary the duration of the experiment at will.

All the experiments were carried out after the animals had been fasting for some time; in between the experiments, they were given a normal complete food ration, consisting of oats, bread, meal, and milk.

More than 200 experiments were carried out in which the gaseous exchange was determined (in terms of carbon dioxide) under the following conditions: 1) when breathing normal air; 2) during the time they were breathing oxygen, 3) during the period of the so-called aftereffect, and 4) when breathing oxygen on two successive occasions.

RESULTS

When breathing air, there is a considerable variation in the gaseous exchange rate.

Thus, in some experiments, rat No. 1 gave off slighly over 120 cm^3 CO_2 per hour, while in other experiments, the same animal gave out more than 150 cm^3. Similar variations were found in other animals.

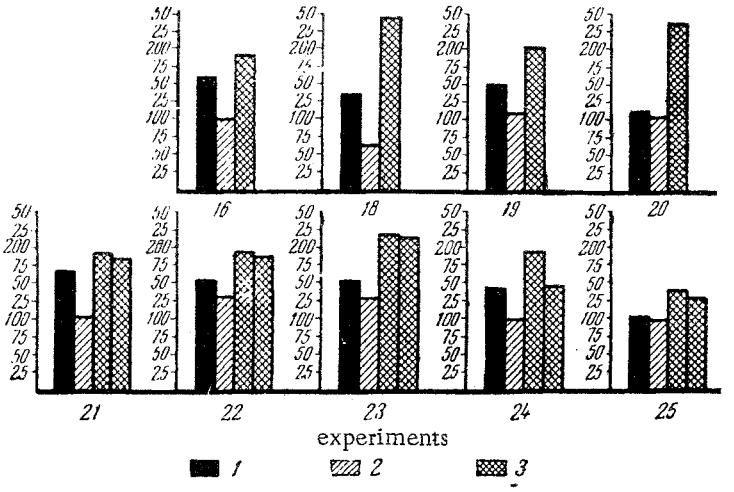

Fig. 1. Excretion of CO_2 (in cm^3) in rat No. 1 when breathing almost pure oxygen. 1) Initial condition; 2) during the breathing of almost pure oxygen; 3) when again breathing air.

On account of these very considerable variations in the gaseous exchange rate, which occurred under constant conditions, we did not take mean values even for separate animals, but found it more useful to make a comparison between the exchange rates in each case when oxygen was substituted for air.

The practical procedure was as follows. At first, the gaseous exchange rate under normal conditions, when air was passed through the chamber, was determined; then the measurement was repeated for oxygen, after which air was once more drawn through the chamber, and the respiratory exchange again determined.

Thus, in each separate experiment the gaseous exchange in a single animal was determined no less than 3 times.

Fig. 1 gives the results of experiment 1 for rats breathing almost pure oxygen, and it can be seen from the shaded column 2 that in most cases there was a relative reduction as compared with the initial value indicated by the black column 1.

There was a considerable reduction in the gaseous exchange rate in experiments No. 16, 18, 19, 21, 24. In other experiments the reduction was less marked (experiments No. 22, 23); in experiments No. 20 and 25 there was practically no alteration in the exchange rate.

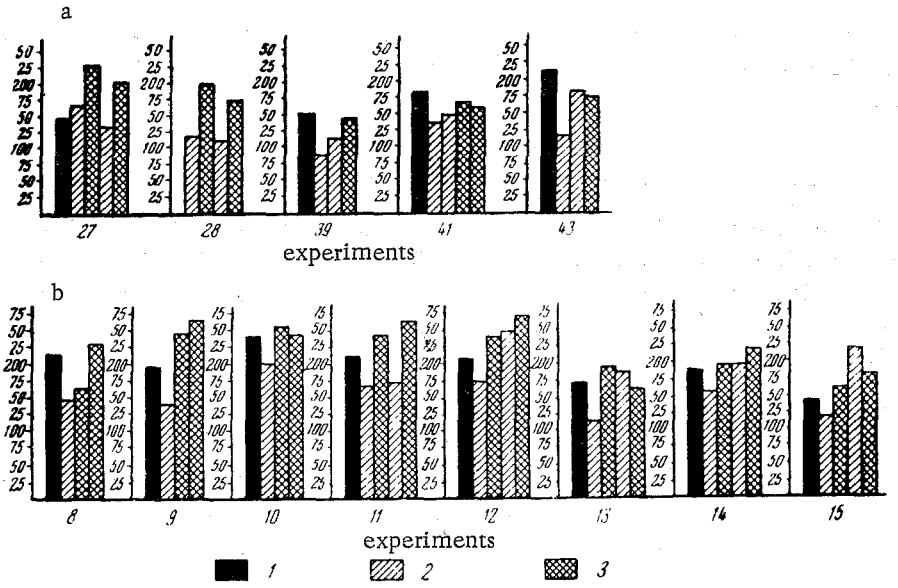

Fig. 2. Excretion of CO_2 (in cm^3) in rat No. 1 after breathing oxygen for two periods (a) of one hour (b) of two hours. 1) Initial rate; 2) when breathing almost pure oxygen; 3) after changing back to breathing air.

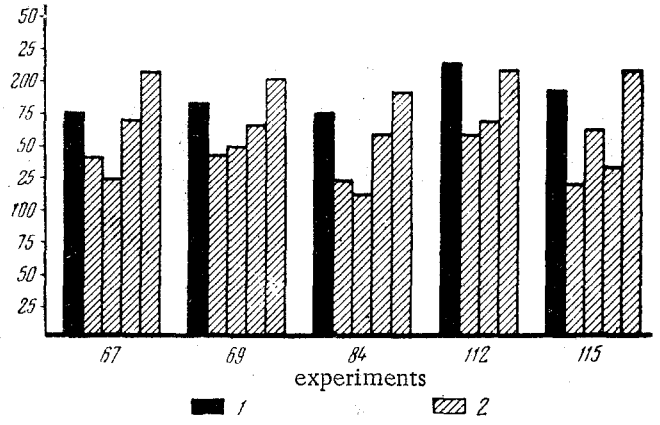

Fig. 3. Relationship between the excretion of CO_2 (in cm^3) and the length of time for which pure oxygen was breathed. 1) Initial condition; 2) during the breathing of almost pure oxygen.

It is important to note that not only rat No. 1, but also in the other 9 animals in whom the gaseous exchange rate was determined under these conditions, there was no case of the carbon dioxide production being raised, but on the contrary reductions were observed from 20 to 47 %.

From Fig. 1 it can be seen that during the aftereffects of breathing oxygen (i.e., after the animal has changed over from breathing oxygen to breathing air containing the normal amount of oxygen) there was usually an increase in the amount of carbon dioxide produced. This can be seen from the results of experiments No. 16, 19, 20, 23, and 24, as shown by shaded columns 3.

From these results it may be concluded that when the animals are transferred after breathing oxygen for a 30-minute or for a 1-hour period to breathing air, there is an increase in the amount of CO_2 given off.

Increase in the production of carbon dioxide during the period of afteraction, continued for not more than 1 hour 30 minutes, after which the rate returned to normal.

If the amount of carbon dioxide given off by the animal is interpreted as indicating the oxygenation of all organic substances and taken as an index of the rate of the catabolic processes in the organim, then it can also be said that the rate of the oxidation processes is loweres during the breathing of pure oxygen, and rises once more when it ceases.

In the next experiments, the gaseous exchange was determined in rats which spent two one-hour or half-hour periods breathing oxygen. For this purpose, first the amount of carbon dioxide given off during the breathing of normal air was determined, the same quantity was then measured when breathing oxygen, then again when breathing air, and once more when breathing oxygen, and so on. The animals were left for the whole time in the chamber, and the gaseous exchange rate determined every 30 minutes, or every hour.

The results obtained are given in Fig. 2, from which it can be seen (experiments No. 11, 27, 28 and 39) that during the period of breathing oxygen (shaded column 2) over a period of 30 minutes or 1 hour, the production of carbon dioxide was markedly reduced, as compared with the normal value obtained when breathing normal air (black column), and that it was increased when the oxygen was withdrawn, both after the first and after the second application.

No appreciable difference was found between the cases when the oxygen was given once or twice. Both in the first and in the second oxygen breathing sessions, there was a reduction of from 20% upwards in the amount of carbon dioxide given off.

The next experiments concerned the gaseous exchange in rats as affected by the duration of the period for which they breathed almost pure oxygen.

From the published results, and from our observations [7, 8, 9] it is known that when oxygen is given in high concentrations, it becomes toxic and causes not only inflammation of the upper respiratory tract, but also of the lungs.

We have shown [8,9] that if frogs, mice, or rats are maintained for long periods in almost pure oxygen, even at normal atmospheric pressure, they die after quite a short time. In these cases, death occurs on the 5th or 6th day, as a result of pulmonary inflammation and edema.

From our observations, we can see that as far as white mice and rats are concerned, a daily sojourn of 4 hours per day for 3-4 months in oxygen causes no organic change in the lungs, and is almost harmless, causing only transitory functional changes, including alteration of the heart rate, respiration, blood gases, etc.

It seemed important to us to find how the gaseous exchange changes in response to prolonged periods in pure oxygen.

Our method made it possible to keep the animals in almost pure oxygen for a long period, and to determine the carbon dioxide, as an index of the gaseous exchange, at any time intervals. Usually, in this set experiments, measurements of the carbon dioxide were made hourly and were referred to 100 g weight of the animal.

For the experiment, 14 healthy rats were used. Over 120 determinations of carbon dioxide were made.

The dependence of the gaseous exchange when breathing pure oxygen on the duration of its action are shown in Fig. 3, where it can be seen that in the groups of 5 or 4 experiments shown, Nos. 67, 69, 84, 112, and 115 indicate that the amount of carbon dioxide excreted changed as described below; results for the other experiments are not given, because their results were the same.

During the first and second hour of breathing oxygen, the amount of carbon dioxide gas given off was reduced (compare the shaded with the black columns), while in subsequent one-hour periods, usually in the third hour, the amount attained the initial value. After 3 hours of breathing oxygen, the amount of carbon dioxide gas given off, as compared with the initial (control) value when breathing air, was increased by 15-20 %.

In control experiments, when the animals breathed air for a corresponding period, no such regular changes in the gaseous exchange rate ensued.

The increased production of carbon dioxide after a 3-4 hour period of breathing oxygen may be due to the greater motor activity of the animals, and to the increase in respiration which occurred frequently.

It is not impossible that the increase in the oxidative processes occurring during prolonged breathing of oxygen is due to its stimulating action on the respiratory tracts. Evidence for this is afforded by the indisputable fact which has often been reported that when breathing high concentrations of oxygen, there is a hyperemia of the upper respiratory passages.

From a large number of experiments and by using a method which allowed a comparison to be made in a single experiment of the amount of carbon dioxide given off when breathing air and oxygen respectively, we may state that when breathing 93-95 % oxygen, there is a reduction in the gaseous exchange rate, which then increases somewhat 1-2 hours after a return to normal air breathing has been made.

SUMMARY

Gaseous exchange was studied in white rats breathing almost pure oxygen. The carbon dioxide output during known time intervals was taken as a measure of the gaseous exchange rate.

This method was used to study changes in the carbon dioxide output, and to compare the values before and after breathing oxygen, and to determine the aftereffect. More than 20 experiments were performed.

In some experiments, almost pure oxygen was breathed, and the gaseous exchange, as measured by the carbon dioxide output, decreased by more than 20%. However it again rose during the period of the aftereffect, which lasted not more than 1½ hours.

Measurements on gaseous exchange were made in healthy rats breathing almost pure oxygen for 3-4 hours. In all, 120 experiments were performed. It was shown that when oxygen was breathed for more than 3 hours, there was some increase in the gaseous exchange rate. This was associated with the stimulating effect of oxygen in the respiratory passages.

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