THE CROONIAN LECTURES. CONTRIBUTION TO THE HISTORY OF THE RESPIRATION OF MAN.

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By W. MARCET, M.D., F.R.S.

LECTURE II.

MR. PRESIDENT AND GENTLEMEN,—Before entering on the subject proper of this lecture I must beg leave to glance at a few of the prominent contributions to our knowledge of the phenomena of human respiration.

In 1849 Regnault and Reiset, from experiments on animals, observed that a marked volume of oxygen was taken in at the lungs which failed to reappear as carbonic acid in the expired air, and they established a relation between the oxygen consumed and the carbonic acid produced. These experiments were confirmed in 1891 by Messrs. Chapman and Bruckner, of Philadelphia.

Dr. Edward Smith, in a paper published in 1859, divides foods into two classes, according to their action on respiration—the excitatory, which increase the production of carbonic acid, and the non-excitants, which have a contrary effect. In the former class he includes, tea, sugar, coffee, rum, milk, cocoa, etc.; also gelatine and albumen, though their effect is less marked. Rum and milk have a very pronounced and persistent action. Two results are prominent in this paper: first, that fats, oils (cod-liver oil), and starch diminish the carbonic acid expired; secondly, that although the ingestion of pure alcohol and rum act as respiratory excitants, still, drinking brandy, whisky, and gin is attended with a diminution of the carbonic acid expired. The elaborate chamber, constructed by Pettenkofer, of Munich, in 1863, and his important inquiries with Professor Voit into the respiration of man should be placed here on record.

In 1874 C. Speck published important papers on respiration. He observed, as will be confirmed in the present lecture, that on returning to natural respiration after forced breathing, and therefore in consequence of increased ventilation of the blood, much less air is expired for a short time than in ordinary breathing in repose; and also that the amount of carbonic acid expired in the after-effect of forced breathing falls considerably below the normal. The oxygen taken from the air is also momentarily reduced.

In 1878 Paul Bert's remarkable book on *The Effects of Barometric Pressure on Respiration* was published, and in it he states that animals dying in closed vessels, and consequently in their own carbonic acid, exhibit precisely the same symptoms as if they had perished under diminished atmospheric pressure, from which he concludes that carbonic acid is absolutely innocuous, and that in such cases death is due to want of oxygen.

In more recent years, Dr. George v. Liebig, of Munich; Messrs. Jolyet, Bergonié, and Sigalas; and MM. Henriod and Richet, have contributed a number of important and elaborate papers on respiration.

Finally, Dr. Haldane, of Oxford, who has been engaged for some years with inquiries on the respiration of man and animals, has shown that while 5 per cent. of carbonic oxide in atmospheric air is fatal to mice, in an atmosphere of oxygen the proportion of carbonic oxide can be increased to 5 or 10 per cent. without fatal results; and if the pressure of the oxygen be raised by one atmosphere, the two atmospheres of oxygen may be mixed with an additional atmosphere of carbonic oxide without harming the animal.

The phenomena of respiration, simple as they appear at first sight, lead on a closer inspection into details many in number and increasing in complexity the further the study is carried. In addition, these phenomena are not precisely the same for everybody; I have therefore repeated the experiments on as many different persons as possible.

The methods adopted in the above-mentioned investigations were very various. Edward Smith inspired through one gas meter and expired through another; while C. Speck

inhaled air under atmospheric pressure from a bell jar suspended over water, and collected the air he expired in a similar receiver, the change of direction in the respiratory current being effected by delicate valves.

Dr. G. v. Liebig, in his experiments, instead of directly measuring the volume of air inspired, obtained it by calculation from the nitrogen found in the air expired, assuming that nitrogen was neither absorbed in the body nor given out of it in the process of respiration.

After the expenditure of much time and labour in the endeavour to obtain the most accurate results by means as simple as possible, and objecting to the use of gas meters on the ground that none could be found sufficiently delicate to allow of the passage of air to and from the lungs without offering any resistance, while valves and absorbing media were open to the same objection, I finally adopted the following method: A cylindrical bell jar of sheet iron, holding about 40 litres, or 1.4 cubic foot, furnished with a scale divided into litres and fractions of a litre, was suspended in water over a pulley, working on friction wheels, and accurately balanced by a counterpoise. To the pulley was fixed a cycloid or lever carrying a weight, the cycloid being so constructed that the effective arm lengthened as the bell jar rose, this arrangement maintaining the receiver under atmospheric pressure at every position in its course. A thermometer and pressure gauge showed the tension of the air inside the receiver. The person under experiment inspired fresh air through the nose, and expired through the mouth into a tube connected with the bell jar—a process which, with a little practice soon became quite natural.

In the later experiments a small additional weight was added to the counterpoise, which gave a very slight ascending motion to the bell jar, and thus did away with the feeble effort necessary to raise it when under atmospheric pressure only.

By means of an uniformly rotating drum and a horizontal style fixed to the top of one of the three bell jars employed, expiratory tracings were obtained on skeleton charts; the abscissæ engraved on the chart measured the number of litres expired, and the ordinates recorded the minutes through which the experiment was continued.

The air collected in the bell jar was analysed for the determination of its carbonic acid or carbonic acid and oxygen, the amount of the former being determined by Pettenkofer's method, and the oxygen in an endiometer of my own construction.

As already stated, the volume of air inspired can be determined by calculation from the volume of nitrogen expired, assuming that the nitrogen in the expired air represents exactly the nitrogen inhaled. To find out experimentally if this assumption was correct, a measured volume of air saturated with moisture was inhaled from one bell jar and exhaled into another, thus showing in a direct manner the volumes of air inspired and expired; at the same time the volume of nitrogen in the expired air was obtained by analysis, and from it the volume of air inspired was calculated. The mean of ten experiments gave a volume of air inspired, as determined by direct observation, almost identical with that obtained by calculation from the volume of nitrogen in the expired air; thus showing conclusively that no appreciable amount of nitrogen is either absorbed or given out from the blood in the phenomenon of respiration, and also justifying the method employed.

If a person, while resting in a recumbent posture in an arm chair and breathing quite naturally, should measure the volume of air he expires, this volume will be found invariably smaller than the corresponding volume of air inspired. A certain volume of oxygen has remained in the body. What has become of it? Formerly this absorbed oxygen was looked upon by some authors as combining with hydrogen to form water, but of this there is no proof. Its amount is subject to great variations even in the same person, while these oscillations appear greater in young people with active tissue change than in elderly persons with a slow and regular metabolism, young people as a rule absorbing more oxygen in a given time than persons of mature age. I have also observed, as will be shown in my next lecture, that absorbed oxygen is intimately connected with the mental process of volition.

The period of the maximum absorption of oxygen is, undoubtedly, within the first hour after a midday meal. This is a time when the carbonic acid expired is low; but the body has to prepare for the forthcoming increased assimilation and tissue change under the influence of digestion, hence, apparently, there is a demand of oxygen by the tissues to be stored up towards these phenomena.

From the following table, giving results of experiments on myself, it will be seen that for a person aged 63 the mean volume of oxygen he absorbed per minute while fasting was practically the same as under the influence of food, being 35.3 c.cm. fasting and 34.6 c.cm. while under the influence of food.

Oxygen Absorbed per Minute (Author under Experiment).

Fasting:

Year 1891 (6 experiments), from 25.7 c.cm. to 42.8 c.cm.; mean, 35.3 c.cm.

Mean time of 2½ hours after full meal:

Year 1891 (6 experiments), from 21.3 c.cm. to 36.7 c.cm.; mean, 30.2 c.cm.

Year 1892 (10 experiments), from 20.4 c.cm. to 46.1 c.cm.; mean, 36.7 c.cm.

Year 1894 (21 experiments), from 27.7 c.cm. to 45.0 c.cm.; mean, 37.0 c.cm.

In the case of three young men who submitted to experiment—all of them from 21 to 23 years of age, strong and in good health—the following results were obtained:

Oxygen Absorbed per Minute.

Fasting.	c.cm.	Nearly 2 hours after Lunch.	c.cm.	Increase after Lunch.
No. 1 (6 experiments)	33.3	(6 experiments), 37.5		12.6 per cent.
No. 2 (3 ")	34.1	(7 ")	50.0	46.6 "
No. 3 (6 ")	34.4	(12 ")	40.5	17.4 "

It will be seen from this table that distinctly more oxygen was absorbed about two hours after a full meal than when fasting; hence it appears that in the case of young people there is a decided increase of the oxygen absorbed at a time when the carbonic acid produced is not far from its maximum. This is, however, not the occasion of the maximum absorption of oxygen which, as stated above, occurs in the course of the first hour after a full midday meal, this is shown by the following figures for that period:

The author (4 experiments), 47.9 c.cm. to 58.3 c.cm.; general mean, 34.0 c.cm.
Assistant (7 "), 56.4 c.cm. to 81.6 c.cm.; " 37.4 c.cm.

The oxygen absorbed added to the carbonic acid produced will indicate the total amount of oxygen taken from the atmosphere, or oxygen consumed. The relation between the oxygen consumed and the carbonic acid produced has been called by Regnault and Reiset the "respiratory ratio,"

and is expressed by the ratio $\frac{\text{CO}_2 \text{ produced}}{\text{oxygen consumed}}$. Now, the value of this fraction varies considerably at all times of the day, under the influence of food, and from other causes, but when calculated for the mean volumes of oxygen consumed and carbonic acid produced in the daytime in a state of rest, it appears to be nearly the same for different people. Thus the mean obtained by Messrs. Jolyet, Bergonié, and Sigalas was 0.864; that obtained on myself was the same, 0.864; the corresponding figure as a mean of 27 experiments was 0.862 for one of my assistants, and 0.878 for another from 20 experiments. The subject, however, requires further investigation, on account of the number of circumstances controlling this ratio, and I have found exceptions to this mean figure into which I am not yet prepared to enter.

There is no direct connection between the CO_2 produced and oxygen consumed, and there is no meaning in the respiratory ratio, unless given as a mean for the whole day in the state of rest, and even this mean is subject to exceptions. I am anxious to make this statement lest I should be misunderstood. It is impossible to trace the history of oxygen taken from the atmosphere of the lungs by the blood corpuscles. This oxygen is carried into the tissues and there detained and stored up according to their requirements. The great increase of oxygen taken in, and the low volume of carbonic acid expired within an hour after a meal, certainly appears to show that on this occasion the tissues store up

within themselves a considerable amount of oxygen in readiness to take part in the increased assimilation and tissue change resulting from the digestion of food. The reverse would take place from a sudden accession of cold when the carbonic acid expired has been found—at all events in my case—greatly in excess of the ordinary proportion of oxygen absorbed. On this occasion it appears as if carbonic acid is formed at the expense of the oxygen stored up in the tissues. This view, arrived at after mature consideration of Hermann's results, does not, I am afraid, agree with that I expressed on a former occasion.

THE DIFFERENT FORMS OF RESPIRATION.

On taking a general view of human respiration, it is found that this function may assume four distinctly different forms, which include the endless varieties of breathing.

The first is automatic breathing in a state of repose.

The second is forced or laboured breathing while the body is in a state of rest.

The third is breathing while under muscular exercise.

The fourth is breathing while the body is in a perfect state of repose, with the mind or imagination actively at work towards the exercise of volition.

I shall make no further remark on the first form, but pass on at once to forced respiration.

If a person, while sitting with his muscles fully supported, should take a series of gasps or forced inspirations, he not only exercises his ordinary muscles of respiration, but brings into play other muscles not usually concerned in breathing in a state of repose, thus increasing the muscular labour, for which an extra amount of heat is required.

The increase of labour is obvious from the fatigue experienced if the forced breathing be continued for three or four minutes in succession, and when lasting for twelve or fifteen minutes the impression is very marked. Now, although as large a volume of air is often breathed under muscular exercise as in forced breathing, no fatigue whatever of the muscles of respiration is produced. The muscles directly concerned in the exercise may show signs of fatigue, but not the muscles of respiration, which have acted a secondary part in conjunction and harmony with the exercise.

The experiment for forced breathing is conducted as follows: The person under experiment breathes automatically into the bell jar connected with the recording drum, and obtains a tracing of his normal breathing in repose; he then takes a succession of deep gasps for one, two, or three minutes, the recording apparatus being kept at work; after that time he relapses into normal automatic breathing while the tracing is continued on the chart for two or three minutes longer. This tracing of forced breathing is characteristic. First, the inclination of the line is considerably steeper than for normal breathing, corresponding to the expiration of a much greater volume of air in a given time; next, on relapsing into ordinary automatic breathing, the line will exhibit a tendency towards the horizontal direction for a few seconds, showing a pause in the respiration, a state of apnoea after which the inclination of the line again rises somewhat beyond the normal, owing to another increase in the volume of air breathed. This second increased expiration, though always present, is, however, but slight; the tracing then returns parallel to that for normal respiration, the physical effects of forced breathing being now over.

A consideration of this curve shows that first of all an increased volume of air is taken into the lungs; this process is laborious, and attended, on that account, with increased combustion, resulting in the production of a slight excess of carbonic acid; this is found experimentally to be actually the case. Next, a certain proportion of the carbonic acid stored up in the blood is displaced by the increased volume of air breathed. This phenomenon is also demonstrated by analysis. On returning to natural automatic breathing there is, as stated above, a pause or state of apnoea, due either to an accumulation of oxygen in the muscles of respiration or to the fact that some of the carbonic acid stored up in the blood having been given out, a quiescent state of the breathing is necessary to allow the blood to charge itself afresh with that gas, and the body containing at the same time, an excess of oxygen absorbed, there is no feeling of want of air.

The next phenomenon observed after the pause is a slight increase in the air breathed beyond the normal. This increased ventilation of the lungs is clearly due to a want of oxygen in the blood, the oxygen present having been to a great extent used up during the pause; a fact showing that such is the case is that this increased breathing is more or less marked according as the pause has been long or short. Thus far the physical character of forced breathing has been described; a few remarks have to be added on its chemical aspect. The phenomena of forced breathing are illustrated by the following diagram:

Let the line A A represent normal or natural respiration in a state of repose. The curve A B C with the sign + will stand for forced breathing, the curve C D E with the sign - for the reaction or after stage following forced breathing; the pause in the respiration will take place while the breathing is going through the curve C D E. The slight curve E F G represents the increase in the respiration beyond the normal after repose. During the forced respiration corresponding to A B C, a certain amount of carbonic acid in excess of normal is exhaled from the blood, and at the same time the quantity of oxygen absorbed is increased. A very small portion of this excess carbonic acid is the result of combustion due to the extra muscular work, the greater part being displaced from the blood. Obviously if such is the case, on filling several bell jars in succession with air expired in forced breathing, the second bell jar will contain a smaller excess of carbonic acid than the first, and the third smaller than the second, less and less carbonic acid being left in the blood as the experiment proceeds. The analyses in four experiments on

myself and three on my assistant confirmed this view. The figures obtained in one experiment for carbonic acid emitted from the blood, when disposed on a chart yielded the following curve of a parabolic form. Sneezing, sighing, yawning, and

sobbing come under the head of forced breathing. In sneezing, for instance, a deep inspiration is first taken, followed by a sudden expiration, which carries out with it a certain volume of carbonic acid from the blood. Immediately afterwards a pause is observed because there is in the blood an excess of oxygen and a deficiency of carbonic acid. From the pause time is given for the excess of oxygen to be used up, and for the carbonic acid in the blood to be increased to the normal.

The third form of breathing is under muscular exercise. In both its physical and chemical aspects it differs greatly from the first and second form. The moment muscular exercise of any kind is taken, the volume of tidal air breathed in a given time is increased; this phenomenon is absolutely automatic and unattended with fatigue. In my experiments the exercise taken consisted of stepping 66 or 67 times per minute, the heels being raised to a height of about 4 inches, when the direction of the line of breathing on the chart gave a fairly straight diagonal, with a much steeper rise than in ordinary breathing in repose. After the exercise had lasted for two or three minutes, the person under experiment assumed the recumbent posture in the armchair, breathing perfectly automatically; the tracing on the chart was now observed to continue in the same direction for a length of time in a great measure proportional to that during which the exercise had been taken; then the inclination of the line became less and less steep till it gradually returned parallel to the normal. The tracing therefore exhibited no pause, as occurred in forced respiration. Forced breathing, immediately following exercise, shortens the period of breathlessness on resuming the state of repose, and it is possible to regulate forced breathing in such a way that after two or three gasps normal respiration follows immediately.

These remarks have a practical bearing; they show that a person much out of breath from muscular exercise, on assuming the state of repose would experience immediate relief from a few deep gasps, and also that a long breath now and then with a short rest, in the course of protracted exercise, would be of help to respiration.

Let us now inquire into the different stages of respiration under exercise. First of all more oxygen is wanted from the air for the heat required for the muscular work, hence a larger volume of air is breathed; at the same time an increased amount of carbonic acid is expired, but this emission of carbonic acid cannot take place at a speed proportional to the rate of its production, and it therefore accumulates in the blood. On arresting the exercise and assuming the state of repose, the excess carbonic acid is given out, and with that

object the lungs have to be freely ventilated; hence the state of breathlessness or dyspnoea after such exercise as running or walking.

Chemical analysis shows that a large excess of carbonic acid is given out on sitting down after exercise, which carbonic acid must have been produced by muscular contraction, as there can be no excess of combustion in a state of repose, for if there were, the temperature of the body would be raised, as the heat produced could not be disposed of in any other way but by radiation, a consideration which led to the following experiment:

Two clinical thermometers were maintained under the tongue while stepping, and left there long enough to be certain of the sublingual temperature, then one of the thermometers was removed, while at the same time the person under experiment assumed the state of repose. After about ten minutes the second thermometer was withdrawn, when both were found to give the same reading; hence there is no excess of carbonic acid formed on resting after exercise beyond a small quantity corresponding to the work done to rid the blood of the carbonic acid with which it is charged.

The dyspnoea after exercise recalls an interesting experiment of Claude Bernard, who injected sulphuretted hydrogen into the circulation of a dog, and after each injection the animal drew a succession of deep breaths, thus getting rid of the gas injected by an increased pulmonary ventilation. The sulphuretted hydrogen could be clearly detected by the odour of the animal's breath and its action on paper moistened with lead acetate. Reading, talking, singing, screaming, coughing, all belong to the form of respiration under exercise. Screaming shows from its tracings that in some cases it is breathing under exercise, in others forced breathing. In the case of singing the records point out that on singing in the sitting posture there may be forced breathing, though not in the standing position; hence the import-

ance of singing standing. In reading, talking, and singing the tracing of the "after stage" is at once parallel with the normal, showing that in these instances there is no breathlessness produced, and no excess of carbonic acid retained in the blood.

I shall beg to conclude this lecture with a few remarks on the exhalation of water from the lungs at different altitudes. The amount of this evaporation must be controlled by three different causes—the atmospheric temperature, humidity, and pressure. Given temperatures and humidity approximately equal, an elevation above the sea level will increase the evaporation together with the lowering of pressure.

When on the peak of Teneriffe in 1878 I selected four stations for experiment—one at the seaside, another at an altitude of 7,090 feet, the next at 10,700 feet, and the fourth inside the shallow crater, at the very summit of the peak, at an altitude of nearly 12,200 feet. The weather was very fine, and the atmospheric humidity exhibited no great variations at the different stations, except at the seaside, where it was decidedly higher. The air expired was breathed through absorption tubes filled with calcium chloride into a bag of known capacity, the time of breathing being also observed. The humidity of the atmosphere was determined with wet and dry bulb thermometers, and the weight of moisture contained in the volume of air inspired was subtracted from the total moisture expired, thus the weight of the water evaporated from the lungs was obtained.

It was found that as the altitude increased more and more water was evaporated from the lungs within a given time, although the amount of this increase was not quite proportional to the increase of altitude, clearly because the loss of water from the blood at increasing altitudes left less to be evaporated, the blood retaining necessarily a minimum quantity of water. We shall return to the subject of respiration at high altitudes in the fourth lecture.

MORPHEA HERPETIFORMIS:

A NEUROLOGICAL STUDY.

By JONATHAN HUTCHINSON, F.R.S., LL.D.,
President of the Royal Medical and Chirurgical Society.

(Continued from page 1196.)

TOPOGRAPHICAL GROUPS.

THE following groups are suggested for temporary use only, and in order merely to facilitate the comparison of cases. They are in the main based on topographical distribution only. Morphœa herpetiformis is the same malady whether it affect only a single twig of nerve or almost the entire body. It is convenient, however, in the course of our inquiry to see how far its examples permit of being arranged in reference to the different nerves affected and to afford some material for estimate of the relative frequency of each. It is to be understood that many of the cases, inasmuch as various nerve territories were involved at the same time, come into more than one of the following groups.

As all the cases which I shall quote have already been published elsewhere in detail, I shall not, with few exceptions, trouble the reader with anything more than a very brief statement of the principal facts. Those interested in the subject must refer to the original narratives.

I.—SINGLE BRANCHES OF THE FIFTH NERVE OR OF THE CERVICAL PLEXUS.

GROUP I.—In this group may be placed examples of morphœa changes occurring in connection with single nerves on the face, head, or neck. Thus streaks of ivory white may occur on the forehead in connection with the supraorbital or other branches of the first division of the fifth nerve, or they may be seen about the eyelids or behind the ear, and on the neck; more rarely on the cheeks, chin, and nose. These all have, of course, their exact parallels in herpes zoster. I do not know of any form of morphœa of the lips which can be compared with herpes labialis. In this connection it may be remarked that it is with zoster only that morphœa is to be compared as to the laws of its distribution, and not with