NEW METHODS OF STUDYING GASEOUS EXCHANGE AND PULMONARY FUNCTION

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THOMAS BOOKS SYMBOL OF LEADERSHIP

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PREFACE

It is an honour for a physician to present a book dealing with physiology and in particular with laboratory problems. Clinical practice has contracted a very great and long-standing debt towards physiology. Practical medicine has always been obliged to deal with biological facts before there has been an opportunity to study them scientifically, and in many instances this is still the case today. Correlations suggested by clinical observation can be better understood after physiological experiments. Though morphological, anatomical and histological methods enable us to discover a multitude of new facts, it will only be through experimental methods that clinical practice will give us a complete analysis of disease from its origin to its cure or fatal outcome. The experimental method will give us deeper knowledge of the processes of defence, compensation, adaptation and repair, and will help to obtain a complete understanding of the pathogeny of primary lesions and their secondary consequences. Physiological experiments become more necessary the more complicated are the pathological processes. The observation of the patient will therefore become really efficient only when the most exact methods given to us by physiology are used to study the normal and pathological functioning of the organs.

Modern methods, indeed, require techniques which are more and more precise, and, we must admit, we would be quite unable to make use of them except after thorough training in such techniques.

For many years Dr. Fleisch has devoted his attention, among many other important problems, to the study of basal metabolism, of pulmonary function and respiratory exchange and of the cardio-vascular function and circulation.

The first task which he set himself was the checking of the accuracy of the instruments which he would use, a most important condition for good research. Now many of the more common instruments will not stand up to severe tests of accuracy; so he began to build his own more accurate instruments which answered the most stringent requirements. Thanks to his perseverence and determination Dr. Fleisch has succeeded. The book which we have the pleasure of presenting will show that the effort has been well worth while. But the careful reader will soon see that we are not here dealing merely with improvements but, for more than one instrument, with completely original designs based on principles first formulated by the author. Here are two examples:

Dr. Fleisch has suggested that time intervals between events which recur periodically should be recorded directly as ordinates. Thus for the heart movement time intervals between pulses are recorded as ordinates. This type of recording makes it immediately and accurately apparent whether we are dealing with a regular heart action or with an arrhythmia. It is easy to distinguish between ventricular and auricular extrasystoles and to recognize any other irregularity. The recording of the duration of the cardiac cycle which Dr. Fleisch has perfected with his "Orthochronograph" represents a step forward of undoubted value. Need I say that this method can be applied to any other biological process, from the fastest to the slowest?

As a second example, for the examination of the respiratory function Dr. Fleisch has introduced the principle of recording the speed of the air current, a principle which can equally well be applied in physiology and in clinical practice. For this purpose he has invented the "Pneumotachograph" by means of which all the characteristics of the respiratory cycle can be demonstrated.

I will not elaborate further. But it is easy to see that these new methods enable old problems to be viewed under a different light and suggest promising new fields of research to physiologists and clinicians.

Although we have in clinical practice some good instruments for measuring man's basal metabolism (Benedict, Krogh, Knipping), Dr. Fleisch has built a new one for the use of the medical practitioner. His instrument is portable and easily handled, and has the great advantage that it gives the result directly in Calories per 24 hours, without it being necessary to make the usual complicated calculations.

The experimental result obtained must be compared to the theoretical standard metabolism for the individual. This can be done by means of Dr. Fleisch's "Metabocalculator," a slide rule with which it is possible to establish in a few seconds, for children or adults, from the age of 1 to 80 years, the theoretical standard metabolism and the deviation between the experimental value and this standard value. This calculator is based on average values which Dr. Fleisch has found by collating all the figures available in the world and these standards give the best estimate for the theoretical values of basal metabolism.

But the crowning achievement among his technical innovations is undoubtedly the "Metabograph" to which Dr. Fleisch has devoted his most sustained effort and ceaseless care. With this instrument, all the currently employed functional tests such as the recording of vital capacity and its subdivision, of maximum expiratory volume per second (Tiffeneau's test), and of maximum ventilation can be effected. This instrument measures, directly and continuously, the spirogram, the ventilation, the production of CO_2 and the consumption of O_2 at STPD, the ventilatory equivalent for oxygen and the respiratory quotient. All these parameters can be recorded at any oxygen pressure, at rest or at any rate of work imposed upon the subject by the Ergostat built by Prof. Fleisch according to an equally new principle. I cannot go into details; the reader — and, above all, those who use the Metabograph — will appreciate Prof. Fleisch's ingenuity in overcoming all obstacles to arrive at a highly satisfactory solution. Sources of error are reduced to a minimum; air-tightness and regulation of temperature are assured. The closed-circuit instrument is constructed in such a manner that rebreathing is impossible, and an excess of pressure in the mask is avoided by using a new type of spirometer, the "double-partition spirometer," which avoids many of the disadvantages met in ordinary spirometers. The elegance of the original process whereby the exact determination and recording of the production of CO_2, of the ventilatory equivalent and the respiratory quotient—all recordings which had not previously been made — will be particularly admired. I shall not say more, though these lines are very inadequate. But it is not necessary here to describe the instrument, but rather to point out its significance in clinical practice and scientific research. I have had occasion to examine patients with the Metabograph and the Ergostat and I am convinced that the pulmonary function during work can be determined with very much greater accuracy than heretofore. The field of investigation is increased remarkably.

Work tests with the Ergostat and the analysis of pulmonary function with the Metabograph are practically indispensable when it is necessary to establish work capacity, to detect a malingerer, or to examine a silicotic in whom an insufficient lung function is usually accompanied by heart failure. Since the average capabilities are known for each age it is possible to define the athletic aptitude of individuals, as well as their degree of training and efficiency.

Our primary goal in clinical practice remains the early diagnosis of sickness. The use of Dr. Fleisch's methods enables us to approach this goal closer than ever before.

All clinicians have a debt of gratitude to Dr. Fleisch; he has given them reliable instruments based on highly sophisticated principles of inestimable value. His book is certainly an outstanding one due to the author's critical mind, his highly original thinking and the clarity of his ideas.

Dr. Fleisch has shown us his methods of work. We do not hesitate to say that, insofar as perfection can be attained, he has attained it. It is now up to the clinical practitioners to prove by rigorous work what an adequate apparatus can do both for science and for practical medicine. Thus will they express their gratitude to Dr. Fleisch.

LOUIS MICHAUD

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I

THE METABOMETER – A PORTABLE INSTRUMENT FOR MEASURING BASAL METABOLISM IN MAN

BASAL metabolism must be determined in the morning when the fasting subject is still in bed and has had no mental excitation. It is only under these conditions that the basal metabolism can be compared to the standard values. All muscular work, however slight, increases the energy exchanges. If the patient is made to come to the clinic in the morning before anything is eaten, the metabolism may be raised and consequently the measurement is no longer reliable, even if the patient rests before the determination. That is why many doctors send their patients to the hospital on the previous evening. After they have spent a quiet night, alone in a room, the patients are in the required condition for the determination of the basal metabolism. This procedure is, however, inconvenient and expensive, and this important clinical examination is therefore frequently omitted.

From a study of the various instruments available for the determination of the basal metabolism it seemed possible to us that a small, portable instrument could be constructed so that practitioners could take it into the homes of their patients to carry out the determination under the required conditions, that is, before any physical exertion and without the emotional disturbance of going into hospital.

To make an instrument portable everything which is not essential must be eliminated. We have found it possible to eliminate the classical spirographic recording of the closed-circuit instruments and to use only direct readings.

The only purpose of the spirogram is to record the beginning and the end of the test and to determine the regularity of respiration. The determination, after all, is nothing more than a measurement of the volume of oxygen and the result will always be expressed by only one figure, the number of Calories per 24 hours. Once this figure is known the spirogram is unnecessary.

Many doctors, however, still require to keep a record of the respiration or to check the regularity of respiration. For these reasons our Metabometer has been designed in a manner which permits direct reading of the basal metabolism and, if it is desired, its recording. The latter has been achieved by means of a recording accessory attached to the instrument.

Many commercial instruments designed for the determination of the metabolism have rubber or plastic bellows. Such bellows are very often the cause of appreciable errors because, being filled with oxygen at the beginning of the experiment, an excess pressure of 10 to 15 mm of H_2O is caused by their elasticity; when they are emptied, on the other hand, a negative pressure which can reach -10 mm of H_2O is produced. Now these alterations of the pressure produce, as we have found (1), a displacement in the respiratory position. At the beginning of the experiment, the respiratory position is displaced by 100 ml or more towards inspiration as a result of the excess pressure; at the end of the experiment, on the other hand, it is displaced towards expiration by reason of the negative pressure in the bellows. The error thus caused can be as high as 8%. We have eliminated this cause of error by balancing the bellows in all its positions by a system of compensating springs.

We have, moreover, attempted to design an instrument which is easy to use and which avoids all the tiresome calculations necessary to express the metabolism in Calories per 24 hours from a knowledge of the volume of oxygen consumed. Our aim has been to obtain the direct reading of the result in Calories per 24 hours.

The principle of our instrument, which we have called the "Metabometer" consists in measuring the consumption of oxygen in a closed circuit by means of the shortening of the bellows. Carbon dioxide is absorbed by soda-lime.

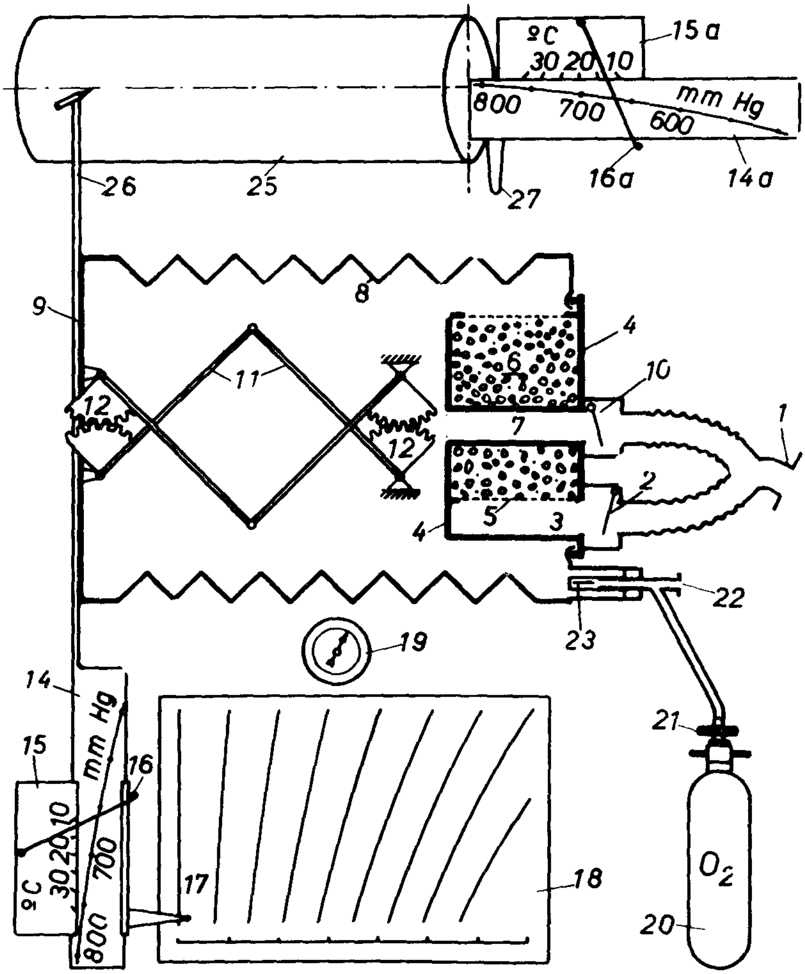

Fig. 1. Schematic diagram of the Metabometer.

Fig. 1 gives a schematic representation of the instrument. From the mouth piece 1 the expired air is directed through the corrugated tube into the lower part 3 of the soda-lime container 4 through the valve 2. This air then passes through the stainless steel lattice 5 and the soda-lime 6 and reaches the bellows 8, thus displacing its movable plate 9 towards the left. At inspiration the air leaves through the central tube 7 and the valve 10, and returns to the mouth piece 1. The rectilinear and parallel movement of the movable plate 9 of the bellows with minimum frictional losses is assured by means of a double system of articulated levers 11 symmetrically connected to the toothed segments 12.

The direct reading of the metabolism is taken by means of the temperature and barometer scales 15 and 14 and the pointers 16 and 17 on the dial 18. At the beginning of the experiment the pointer 16 is placed at the temperature corresponding to the temperature inside the bellows. The vernier 15 is then moved vertically until the pointer 16 cuts the scale 14 at the point corresponding to the atmospheric pressure read on the barometer 19.

When the respiration has become regular, the dial 18 is moved to the right or left until the tip of the main pointer 17 falls at the end of an expiration onto the zero line of the dial 18. The chronometer is started at the same time. The position of the pointer 17 on the dial 18 is noted, always at the end of an expiration, after 4 and 8 minutes. The dial 18 reduces the experimental conditions of temperature and pressure to standard values (STPD). We have used the figure of 4.825 Calories per liter of oxygen STPD for the calibration of the dial 18. This is the equivalent most commonly used in the United States.

The reading after 4 minutes permits a check of the regularity of respiration and the consumption of oxygen; the reading taken at 4 minutes, multiplied by 2, must differ by less than 10% from the reading taken after 8 minutes. If the difference is 10% or more, it indicates a respiratory irregularity, a change in the respiratory position or an irregular consumption of oxygen, or even a leak in the mouth piece or the nose of the subject; in these cases the experiment must be repeated.

The control of the metabolic rate during the two periods of the experiment replaces the check on the regularity of the respiration which is possible by the usual recording methods.

It is necessary to ensure that the respiration is regular when the test begins and that the pointer 17 moves steadily to the right at each expiration. If, after the beginning of the experiment, this displacement is not constant, it is better to start again by returning the dial 18 and the chronometer to zero.

If at the end of a test the respiration has become irregular the mean value can be interpolated. The fact that the 8-minute period does not end at the end of a respiratory cycle is of no importance because a complete extra respiration increases the value found only by about 1%.

The container 6 contains 1 kg of soda-lime enclosing 0.5 liters of air; it is essential that the amount of air in the soda-lime should be large; in this way the expired air remains in contact with the soda-lime during the whole subsequent inspiration so that the CO_2 is completely absorbed.

The bellows have a capacity of 7 liters so that the largest values of basal metabolism can be recorded. Before the mouth-piece 1 is applied to the patient, the bellows should be filled to about one-eighth of their total displacement so that there is enough air for the inspiration. They are later filled with oxygen from the cylinder 20. This cylinder is 18 cm long, 5 cm in diameter and weighs only 390 grams with its stop-cock; it contains approximately 20 liters of medicinal oxygen and is sufficient for about 5 measurements. The stop-cock 21 is opened and the opening 22 is closed with a finger. Oxygen enters the bellows through a valve. If the stop-cock 21 is not properly closed the leaking oxygen does not affect the test because it escapes through the opening 22. We have been careful to design the instrument itself without any stop-cocks since they frequently develop faults such as incomplete closing or jamming.

The instrument is equipped with a barometer 19 and a thermometer, which show the experimental conditions of pressure and temperature. The temperature is measured inside the bellows.

The Metabometer gives directly the number of Calories per 24 hours. This experimental value is compared to the standard basal metabolism obtained with the aid of the usual tables or nomograms or with our "Metabocalculator."

The Metabometer can also be used as a spirometer for measuring the vital capacity. The pointer 17 is placed at the bottom of the dial on the liter scale. One of the corrugated tubes is placed over the two valves 2 and 10 to block them. The other corrugated tube is attached to the tube 23 from which the stopper-valve is removed. The air expired by the patient therefore enters the bellows directly without passing through the soda-lime. Since the maximum volume is 7 liters, vital capacities up to this limit can be measured.

The container 6 can hold about 1 kg of slightly damp soda-lime. It should be stirred from time to time so that the air does not always follow the same path over the grains. To do this the block 4 is removed, the soda-lime is spread over a large sheet of paper, stirred and replaced in the container without the smaller pieces. About 20 determinations can be carried out with 1 kg of soda-lime.

It is natural to ask whether this method of the direct reading of the metabolism is sufficiently accurate compared to the recording of the respiratory curve. To answer this question we carried out 127 double determinations with simultaneous direct reading and recording. 22 experiments had to be discarded because the trace of the recording was irregular. In these cases the readings at 4 and 8 minutes did not satisfy the above-mentioned conditions. For the other 105 experiments the discrepancy between the corresponding determinations was represented by a standard error of $\pm 2.07\%$.

The Metabometer we have described can be delivered for direct reading only. As many clinics prefer a recording instrument, a special recording device can be attached to the instrument. A sheet of millimeter paper of international size A4 (280 mm by 180mm) can be fitted to the drum 25 (Fig. 1). The ball point marker 26 marks the respiratory movements along the horizontal axis.

To obtain the recording of the consumption of oxygen reduced to normal conditions (STPD) it would have been necessary to interpose a very clumsy reduction mechanism between the moving plate 9 of the bellows and the marker 26. We have designed a more satisfactory system which allows the direct recording of the metabolism in Calories per 24 hours without any complicated calculation; its description is as follows:

The variations in temperature and atmospheric pressure cause a change not in the displacement of the marker 26 but in the speed of rotation of the recording drum 25. A synchronous motor inside the drum 25 rotates the drum itself by means of a roller which can be moved along a cone attached to the drum. The position of the roller and therefore the speed of rotation of the

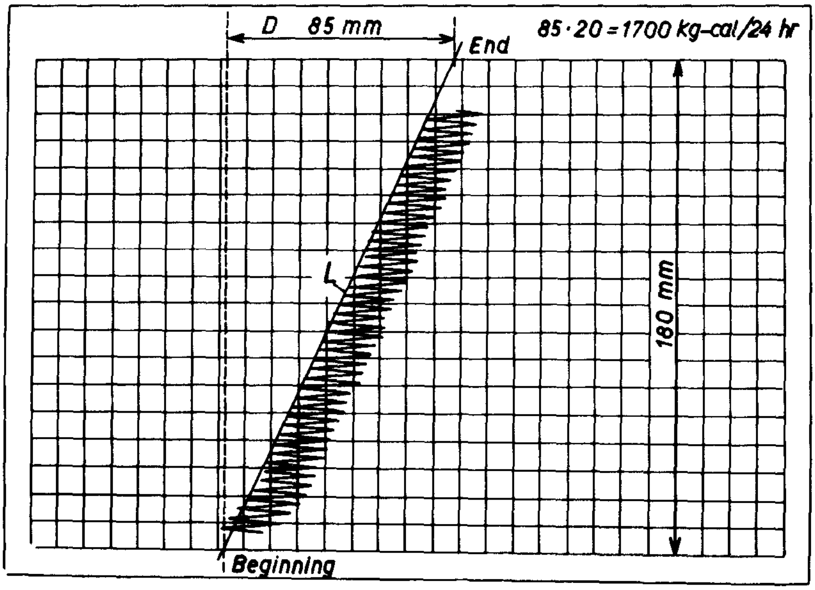

Fig. 2. Schematic diagram of the recording of the respiratory movements.

drum is chosen according to the barometric pressure and the temperature. In this way the system comprising the scales 14 and 15 and the pointer 16 is identical with the system 14a, 15a and 16a. The pointer 16a is first set so that it indicates the temperature inside the bellows; the lever 27 is then lowered and the scale 14a moved to the right so that the position of the pointer 16a corresponds to the barometric pressure. The motor is engaged and a recording made for any length of time, say 8 or 12 minutes. At the end of the experiment the paper is removed and a straight line drawn to correspond to the expiratory positions (Fig. 2).

This straight line is produced on both sides to intersect the margins. The distance between the two points of intersection expressed in millimeters is multiplied by 20. The result is the number of Calories per 24 hours. It is essential that the width of the paper should be 180 mm because the calculation is based on this figure.

Since this system for obtaining the consumption of O_2 under STPD conditions by means of the variations of the speed of rotation of the drum is new, it will be proper to add a few supplementary explanations: The consumption of O_2 during time t at a low barometric pressure or at high temperature must be reduced

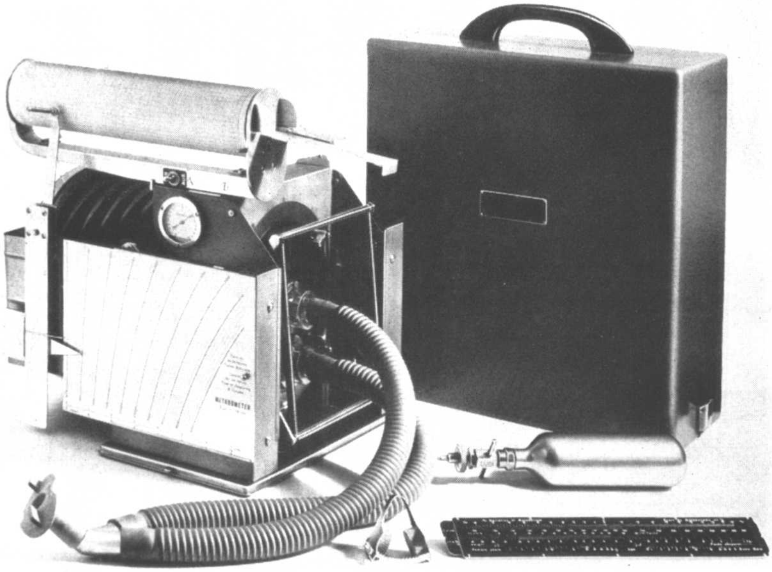

Fig. 3. Photograph of the Metabometer.

to STPD conditions and divided by the time t to obtain the consumption per minute of STPD O_2. In our system, instead of reducing the volume, we increase the time t by altering the speed of the recording drum. The mathematical expression for the consumption of O_2 STPD per minute is:

$$\dot{V}_{O_2} = \frac{V_O}{t}$$

where V_O is the consumption of O_2 STPD in t minutes.

$$V_O = V_X \cdot R$$

V_X is the ATPS volume of O_2 and R is the reduction factor.

We therefore obtain the expression:

$$\dot{V}_{O_2} = \frac{V_O}{t} = \frac{V_X \cdot R}{t} = \frac{V_X}{t/R}$$

The application of this equation enables us to adjust the speed of rotation of the drum in such a way that the projection of the recording on the margin of the paper gives the following result: 1 mm corresponds exactly to 20 Calories per 24 hours.

Fig. 3 shows the Metabometer[1] with the recording device.

[1]The Metabometer is distributed in the United States by Instrumentation Association, 77 West 60th Street, New York 23, N.Y.