THE DETERMINATION OF BASAL METABOLISM BY THE "RESPIRATORY-VALVE AND SPIROMETER METHOD" OF INDIRECT CALORIMETRY, WITH AN OBSERVATION ON A CASE OF POLYCYTHEMIA WITH SPLENOMEGALY*

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I. Introductory

THE *Science of Calorimetry.* Probably no single departure in medical science has been so productive of significant results in the establishment of definite biological standards, and in the yielding of exact clinical data upon the metabolic life processes of the individual, as has that chapter of observations which began with the measurement of the respiratory exchange by Regnault and Rieset in 1850 and the computation of heat production by Pettenkofer and Voit in 1862, and the invention of the respiration calorimeter by Rubner in 1894, and which culminated, through the skill and genius of Atwater[1], Rosa[2], and Benedict[3], in the perfected respiration chamber calorimeter, as installed and operated to-day by trained corps of workers at the Russell Sage Institute of Pathology in New York, and the Nutrition Laboratory in Boston. Through the numerous studies made by trained workers upon these calorimeters and other forms of respiratory apparatus—foremost among which must be enumerated the elaborate series of determinations by Benedict[4], Carpenter[5], Lusk[6] and Collaborators, under the titles "Animal Calorimetry" in the *Journal of Biological Chemistry*, 1912–1915, and "Clinical Calorimetry" in the *Archives*

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*From the Clinical Laboratories of the Royal Victoria Hospital, Montreal.

of Internal Medicine for 1915–1917, and also in the various publications issued on this subject by the Carnegie Institution from 1907 to 1915—abridged computations have been tabulated, curves plotted and normal standards established, so that the complex calculations involved in this work, and the extensive preliminary data required for accuracy in it, are being rapidly reduced to their simplest terms. The same set of workers again, with whom must be included Boothby and Peabody, Eugène and Delafield Du Bois, Means, Higgins, Henderson and others, and, in a less technical but very vital sense, Joslin, Allen and Edsall, have, by determining the metabolism in various pathological states, established the clinical significance of altered heat values especially in those obscure conditions of disordered internal secretions and blood or tissue regeneration, the recognition of which was so well described by the late Dr. Theodore Janeway[7], in his brilliant Address before this Association, as one of the main functions of the modern consultant.

Finally, the various forms of apparatus in use to-day for the determination of respiratory exchange and heat production, from the complicated Atwater-Rosa calorimeter down to the simple Tissot spirometer and Douglas bag, have been subjected in all their details to an exhaustive comparative study by Dr. Carpenter[5], which has been published with full descriptions and diagrams by the Carnegie Institution of Washington. Thus, in very recent times, the science of calorimetry, that is, the calculation of the heat production of the individual, has been reduced from an abstract physical science to a practical subject within the grasp of the ordinary student of medicine, and, by an admirable coöperation of workers and resources, has been brought within the range of easy clinical application in any hospital of modern staff and equipment. These results of the combination of executive genius, unselfish scientific work, organized hospital and laboratory resources, and beneficent legislative support, which underlies the present status of the subject of respiratory metabolism in this country, is surely a triumph of which twentieth-century medicine may well be proud.

Definitions. *Basal Metabolism* is the term applied to the heat production of an individual in the fasting and resting state, and may be estimated in a given case by the calculation of the total calories produced per hour, and per square metre of his body surface area. It is usually expressed in terms of per centage of the basal metabolism of normal individuals of the same age and sex, quantities which have been established through the series of determinations on normal subjects made at the Russell Sage Institute of Pathology, and elsewhere.

The determination of the heat production of an individual is known as the *Science of Calorimetry*. It may be carried out by two methods, termed respectively, direct and indirect. By *Direct Calorimetry* is meant the estimation of heat *elimination*, that is, the heat given off by radiation, conduction, and vaporization, as directly observed and estimated during the time the subject is confined in a closed air chamber, known as the respiration calorimeter. *Indirect Calorimetry* is the determination of the *heat production*, and may be expressed by the ratio of the carbon dioxide and oxygen given off during a given time in a known volume of air to each other, and to the height-weight curve or surface area. This indirect method may be carried out in one of two different ways, the so-called "closed circuit" and "open circuit" methods.

In the *closed circuit* method of indirect calorimetry the expired air is conducted from the patient directly through bottles containing soda-lime and sulphuric acid of known weight which deprive it of its carbon dioxide and water respectively, while the oxygen needed for absorption is introduced from a weighed container; the amount lost of carbon dioxide and water are determined by weighing the receivers before and after the experiment, and the oxygen introduced is computed by weighing in the same way. This is the method followed in the Benedict apparatus, and the Atwater-Rosa calorimeter at the Russell Sage Institute is supplied with a similar equipment, so that with it both direct and indirect methods of calorimetry are carried out on the same patient and are used to check each other in the routine investigations carried on.

In the *open circuit* method of indirect calorimetry the expiration of the subject is not analyzed in the apparatus, but he breathes in and out of tubes separated from each other by expiratory and inspiratory valves, from which latter the expired air is measured in a tank meter or bag for subsequent gas analysis. This method is that followed in the Zuntz-Geppert apparatus, the Tissot spirometer, the "respiratory-valve and spirometer" method described and figured here, and the Douglas bag.

II. The "Respiratory-Valve and Spirometer" Method of Indirect Calorimetry

As stated, this is an open circuit method, similar in principle and apparatus to that of the Tissot spirometer, which is described and figured in the monograph by Carpenter[5] (p. 64). In it the patient is connected by tubes provided with expiratory and inspiratory valves with a spirometer tank in which a known volume of his expired air is collected during the experiment, from which samples are withdrawn and analyzed on the Haldane gas analysis apparatus for their percentage content of oxygen and carbon dioxide, the ratio of these gases to each other and to the volume of expired air breathed into the tank during a given time at a standard temperature and pressure, furnishing the data for computing the patient's heat production.

While not intended to replace the calorimeter chamber, which, as a means of direct computation and for the final checking of standards cannot be dispensed with, this method has a very wide range of usefulness. The apparatus is simple and relatively inexpensive, and the method is one of easy application to the patient, and requires a much shorter time of attachment than the stay demanded in the respiration calorimeter, while the results obtained in the hands of reliable technicians are found to be practically identical with those by direct calorimetry. In his comparative study of the methods of investigating respiratory exchange, Dr. Carpenter gives the Tissot prominence as being both reliable, and valuable from its simplicity and easy application. His recommendation of it is emphasized by Yandell Henderson[8] in a recent communication.

The respiratory-valve and spirometer method (of which the Tissot is the best-known example, and of which it may be taken as the type) was that followed by Dr. Walter M. Boothby at the Respiration Laboratory of the Peter Bent Brigham Hospital, and is that now conducted in his laboratories at the Mayo clinic. During the winter of 1915–1916 it was the privilege of the writer to spend a month at the Brigham Hospital Laboratory under the kind tutelage of Dr. Boothby and his able assistant and associate, Miss Irene Sandiford, with the result that the following summer a spirometer was installed at the Royal Victoria Hospital, Montreal, and the work initiated here under their personal instruction, and through the support of a grant from the James Cooper Fund for Medical Research. A full description of the technique of the "respiratory-valve and spirometer" method as carried on by Dr. Boothby and others in this country, and of the modifications introduced at his suggestion on the spirometer figured here, should be of interest, and is one of the objects of this communication. In this connexion, I would especially acknowledge to him and Miss Sandiford the abridged calculation sheet which is published later in this communication.

Description of Apparatus. The original Tissot spirometer[9], (designed in France) differs somewhat in construction from the modification figured in this article, and is supplied with an automatic water siphon counterpoise, and special (Thiry) valves and glass nose pieces. The principle is, however, identical, the changes introduced being simply those indicated by convenience, economy, or greater simplicity. The construction of the apparatus in use here will be readily understood from an examination of the diagram of it (Fig. 1) kindly made for me by Dr. Louis Gross. In it the spirometer bell or tank, which is here of a capacity of about 200 litres, is made of aluminum (in this spirometer), or of copper, preferably the latter, and must of course be absolutely air-tight. It is inverted upon and received into an ordinary galvanized iron ash barrel (A), which is filled to within about eight inches of its brim with water, upon which the spirometer floats, and into which it sinks by its own weight when deprived of counterpoise. The spirometer is attached to a lead counterpoise (G), which holds it in equilibrium, by a steel measuring tape (B), graduated to 200 cm., which passes over a steel balance wheel (D), so placed that its outer circumference stands directly over the centre of the spirometer, over the surface of which the tape must run smoothly with a minimum of friction. Air is admitted into, and discharged from the barrel through two one-inch iron pipes which pass vertically downwards on either side along the outer wall of the receiver (A) to near its bottom where they are bent inwards piercing its sides, and passing along its floor to near its middle are turned sharply at right angles to pass vertically upwards to a point about two inches above the level of the water which it contains, thus communicating with the cavity of the spirometer. The external openings of these pipes are supplied with ordinary three-way gas-plumbing stop-cocks, the surfaces of which are well ground and greased so that they turn readily and can be opened and closed with a key instantaneously, at the beginning and end of an experiment, and which are provided with stops preventing them from turning beyond the three direc-

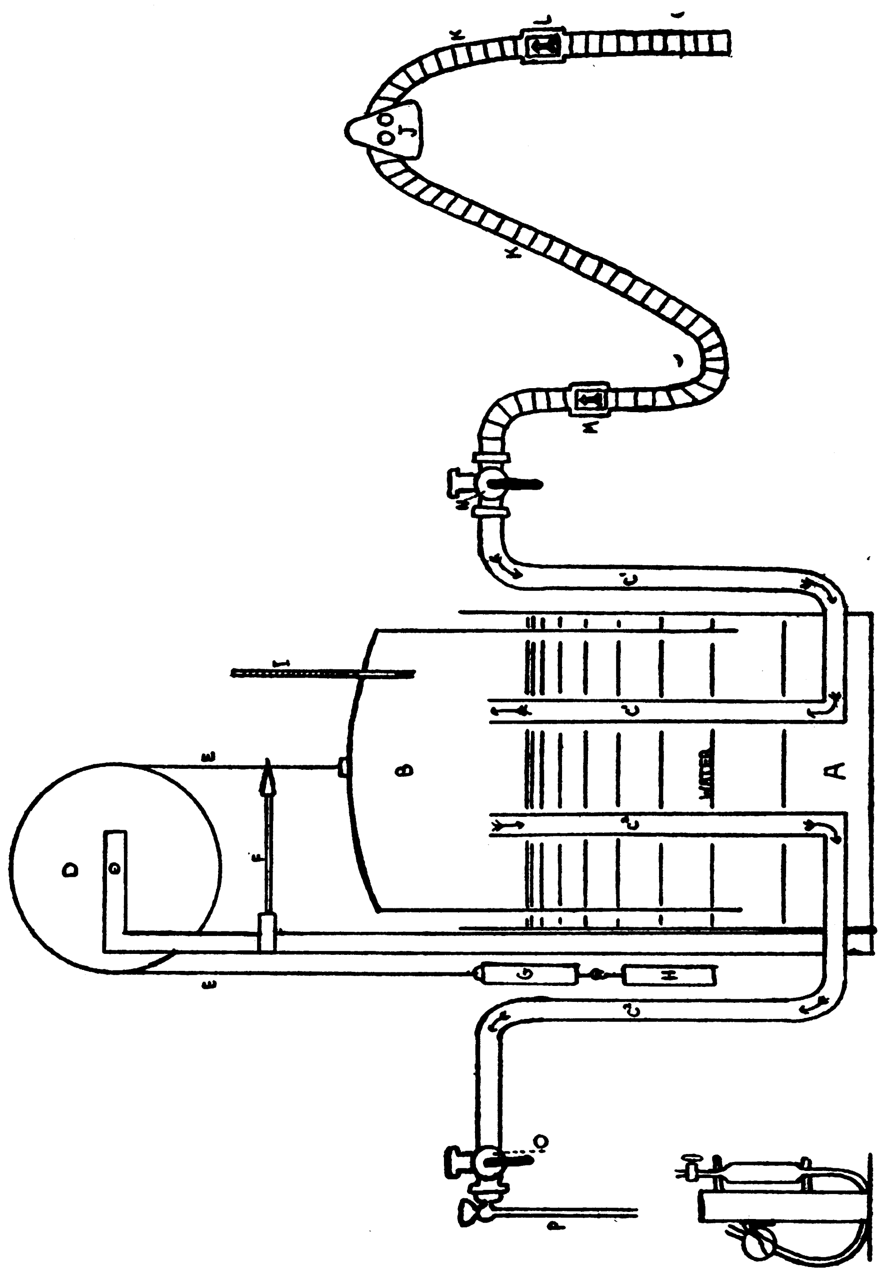

FIG. 1.—VERTICAL SECTION THROUGH RESPIRATORY VALVE AND SPIROMETER APPARATUS (MODIFICATION OF DR. WALTER M. BOOTHBY)

Fig. 1—Key to lettering of illustration showing Vertical Section through Respiratory Valve and Spirometer Apparatus

A. Galvanized iron vat, three-fourths filled with water, on which the bell of the spirometer floats, and which acts as a seal.

B. Bell of the spirometer tank made of copper or aluminum in which the expired air is collected for measurement and analysis.

C^1 C^2 Iron pipes passing from without up through the floor of tank to a point above the level of the water, and permitting the passage of air in[1] and out[2] of the spirometer.

D. Balance wheel for suspension of spirometer bell by

E. Steel tape graduated in centimeters for measurement of volume of expired air collected (i.e. height to which spirometer ascends).

F. Indicator needle for reading height of spirometer before and after experiment.

G. Lead counterpoise, so adjusted as to maintain tank in equilibrium at about two-thirds of its height.

H. Additional weight added during experiment to allow tank to rise gently with each expiration (by negative pressure).

I. Thermometer for ascertaining temperature of expired air at close of experiment.

J. Mask applied to patient's face during experiment. The two holes admit the entrance and permit the exit, respectively, of the inspired and expired air.

K. Corrugated flexible rubber tubing passing from either side of the mask and connecting it with

L. An inspiratory valve, communicating with the outer air and

M. An expiratory valve, attached to the flexible tubing, and to iron pipe leading into spirometer through

N. Three-way valve which connects the inlet pipe C^2 of spirometer (a) with the patient, or (b) with the outside air, or which (c) closes the spirometer to both.

O. Three-way valve which connects the outlet pipe C^2 of the spirometer (a) with the outer air (as in emptying the spirometer), (b) with gas sampling tubes for withdrawal of samples, or (c) closes spirometer to both.

P. Gas-sampling tap. A small stopcock with rubber tubing attached, inserted into one outlet of the three-way tap N.

Q. Burette with gas-sampling tubes into which samples of expired air are withdrawn through the stopcock P. at close of experiment for subsequent analysis.

tions desired. The valve (N), at the entrance pipe connects it with the flexible tubing carrying the expired air from the subject into the spirometer, and may be opened (*a*) to the patient and the spirometer, (*b*) to the spirometer and outer air, but closed to the patient, and (*c*) may be closed to the spirometer. The valve (O), at the exit pipe is blocked in one of its openings by a small stopcock (P), through which air may be withdrawn from the spirometer at the close of the experiment to the gas sampling tubes. The exit valve may thus be (*a*) open to this gas sampling tap and the spirometer, (*b*) open to the spirometer and the outer air, or (*c*) closed to the spirometer.

The apparatus for the transmission of the expired air from the patient to the spirometer used here (see Fig. 2) is a mask obtained from the H. N. Elmer Co., 1140 Monadnock Block, Chicago (agents for the Siebe, Gorman Co.), and figured at page sixteen of their catalogue. To it are attached rings for the attachment of tapes to tie it over the patient's nose and mouth. The flexible corrugated rubber tubing (K) passing from the mask to spirometer may also be obtained from the same source. It may be replaced by ordinary hose tubing if desired (as in this spirometer) except near the mask, and at the bend for the expiratory valve, where the flexible tubing should be used. The inspiratory and expiratory valves used in the course of the tubing from the patient are in this apparatus the ordinary Douglas' valve, in which a back current of air is prevented by a mica flap. They do not respond so readily to changes in the direction of air as the Tissot valves and so have not so high a percentage of efficiency (Carpenter), but give sufficiently constant results for use. *During the experiment they must be fixed in the vertical position, with the mica flap horizontal.* The inspiratory valve should not be placed at the end of the intake tube, but separated from the outer air by a short length.

The counterpoise (G) used in this apparatus is an ordinary piece of lead tubing closed below and filled with shot to such a weight that when it is in position, with the spirometer valves open, the tank will stand at equilibrium at about half of its height. On its bottom is a hook for the attachment of the additional weight (H) which must be such as to allow the tank to rise gently with each expiration.

The subject of the counterpoise to be used, and of the additional weight to be added during the experiment is of interest. In the original Tissot, and in several laboratories in this country, a constant equilibrium of the tank at all points of its height is maintained by means of a water siphon balance, but it has been shown by Dr. Carpenter[5] (p. 217) that such an automatic arrangement is unnecessary, and that trifling changes in the counterpoise do not signify.*†

The additional weight to be added during the experiment varies slightly with different apparatuses. It must be sufficient to allow the tank to rise gently with each expiration but not enough to send it up without this. In this spirometer it is 200–250 gms.

Description of technique. The preliminary essential for basal metabolism is that the patient must be in the *fasting* and the *resting* state. The experiment is therefore preferably conducted in the early morning, and directions are given in the ward that no nourishment is to be taken after six o'clock the previous night except a cup of *Kaffee-hag* or tea at 7.00 a.m. if desired. A new patient should be visited in the ward the previous day by the operator and the procedure explained and all anxiety removed. At 8.00 a.m. he is sent to the laboratory in a bed with three pillows, accompanied by a nurse who remains with him throughout the experiment, and is trained to make certain necessary observations. From the moment he enters the laboratory absolute quiet is essential, the door being closed and no conversation above a low tone permitted (for the psychological as well as actual effect).

The observation is divided into the preliminary period and the experiment proper, which is run in two periods of eight to fifteen minutes according to the character of the case. In the *preliminary period* the patient must lie at complete rest in a comfortable position without speaking, during which time his temperature and full minute pulse and respiration are taken and charted by the nurse, as also his blood pressure and a pneumograph tracing if desired, the operator meantime emptying the spirometer of air and placing

* The writer made several observations upon various weights of counterpoise before seeing Dr. Carpenter's article with confirmatory results.

† As a result of an enquiry made of Dr. Carpenter through Dr. Paul Roth upon the subject of the adjustment of the weight of the counterpoise, I received the following reply:

"Dr. Carpenter tells me that he balances the spirometer as perfectly as possible with the bell half-way up (or down). To check it up he adds *for instance* 40 grammes on the bell to cause it to sink slowly and down to the bottom. He returns the bell to the *half-way* position and puts the 40 grammes on the counter weight this time. If perfectly balanced the *smallest weight* which will cause the bell to sink to the bottom *from the half-way position* will also, when transferred to the counter weight, cause the bell to rise just to the top. If, for instance, the weight will sink the bell but will not raise it proportionally when transferred to the counter weight, it indicates that this counter weight is yet too small."

all in readiness for the experiment. Towards the close of the preliminary period the mask is applied to the patient's face and tied firmly in place by the tapes attached, two additional tapes being added around the head and over the mask to keep it tightly adjusted without the slightest leak (which may be tested for by applying soap bubbles). Care must be taken that the patient is perfectly comfortable and that his respiration is quite unimpeded, the slightest obstruction leading to erroneous rises in the metabolism figures. The tank is then "washed" several times with the patient's air by admitting and discharging a small quantity through the entry and exit valves. After the last washing a cushion of the patient's air is left in the spirometer and both valves are closed, the counterpoise is attached, and height of spirometer read.

To begin the first period of the experiment, the operator adds the additional weight to the counterpoise and immediately connects the patient with the spirometer by suddenly opening the entry valve, preferably at the end of an expiration, and at the same moment starting the stop-watch. The spirometer should rise very slightly with each expiration and should be allowed to ascend to about two-thirds or three-fourths of its height as desired. Meantime the operator records the time of starting, and the nurse records the full minute pulse, and half minute respiration every two minutes, and notes any changes in the patient's condition or breathing on a chart which becomes part of the record. The period is closed by simultaneously closing the entry valve and stopping the stop-watch, removing the additional weight, and taking readings of the height to which the spirometer has ascended, the temperature of thermometer, the duration of period by stop-watch and the barometric pressure, and recording these data on the calculation sheet. The difference in the height of the spirometer at the start and finish is the rise of the spirometer due to the air expired in the time shown by the stop-watch. The patient is now released from the mask and samples are taken. This is done by first allowing a portion of the air in the spirometer to escape through the exit valve (the counterpoise being removed, so that the tank will sink by its own weight), in order that the central part of the contained air may be obtained for the samples, and then drawing off duplicate samples through the small gas sampling tap (which must be first "rinsed" with the patient's air for some minutes). The barometer is read and recorded at the close of each period. After the end of the second period the patient is returned to the ward, where his absolute weight and height are taken and checked by a second observer (as

Fig. 2.—"Respiratory-Valve and Spirometer" Apparatus for Determination of Basal Metabolism as in use at the Royal Victoria Hospital, Montreal.—(Technique of Dr. Walter M. Boothby, applied by M. E. Abbott).

The picture is taken as in the middle of a period, except that the additional weight has been removed from the counterpoise. The mask is seen attached to the face of the patient, with the nurse seated as during the experiment, and the spirometer has risen to half its height. The flexible corrugated rubber tubing attached to the mask, and the entry and exit valves of the spirometer, are obvious details of interest. Photograph by Mr. H. H Wootton, of the Royal Victoria Hospital.)

are all readings) and recorded. The samples obtained are analyzed in duplicate by the Haldane apparatus for the CO_2 and O_2 percentage, all figures used being retained on the sheets.

The Calculations. As may be gathered from the above description of the technique, the following data have been obtained from the experiment for the calculation of heat values and basal metabolism: (*a*) The volume of air in the spirometer; (*b*) the time in which this volume was expired; (*c*) the temperature of the expired air in the spirometer; (*d*) the barometric pressure (which is required in order that all calculations may be reduced to standard pressure for comparison with each other); (*e*) the percentage of oxygen absorbed, and carbon dioxide exhaled; (*f*) the height and weight of the patient; (*g*) the age and sex of the patient, whereby he may be compared with the normal.

From these data it is required to calculate (*a*) the volume per minute; (*b*) the CO_2 per kilogramme per minute; (*c*) the oxygen per kilogramme per minute (*d*) the ratio of carbon dioxide exhaled to oxygen absorbed, *i.e.*, the respiratory quotient; (*e*) the calories per square metre per hour (*i.e.*, the basal metabolism); (*f*) the basal metabolism in terms of percentage of the normal standard for the sex and age of the patient.

ROYAL VICTORIA HOSPITAL

Calculation Sheet for Respiratory Metabolism*

Case No. . .24405	Temp. . . . . . .98° F.	Date, Dec. 13th, 1916.
Name. . . . .Thos. Dougall.	Height. . . . . .163·1 cm.	
Age. 58	Weight. . . . . .43·73 kg.	Period. . . . . . II.
Diagnosis. . Polycythemia and Splenomegaly.	Surface Area. 1·42 sq. m.	

Barometer.	750·3 mm.	(*a*)	Log Fact. spir.	·1652
Temp. Spir.	14·5° C.		" Spir. diff.	·5775
			" Fact. S.T.P.D. . . .	·9629
Spir. Start.	55·65 cm.		"	
End.	17·85 cm.		" Total vent.	·7056
			" Time.	·9122
Diff.	37·80 cm.			
			" Vent. per min. . . .	·7934 = 62· l.

* This sheet is a copy of the printed form for calculations on respiratory exchange constructed by Dr. Boothby and Miss Sandiford for use in the laboratory of the Peter Bent Brigham Hospital and Mayo Clinic, and by their kind permission introduced at this hospital also.—(M. E. A.)

Time	Start..........	9.40 a.m.
	Duration......	8m.10s. = 8.17 min.
(b)		
CO_2	Expired........	3·14%
"	Inspired.......	0·03%
"	Produced......	3·11%
Log	CO_2 produced..	·4928
"	Vol. per min...	·7934
"	CO_2 per min...	·2862 = 193 cc.
"	Weight........	·6405
"	CO_2 per kg. min.	·6457 = 4·42 cc.
"	O_2 per kg. min..	·6982
(d)		
Log	Resp. Quot.......	·9475 = .89
Normal Comp.......		35·2 Cal.
Metabolism........		+28·7 %

(c)		
O_2	Inspired, corr.....	20·98%
"	Expired..........	17·57%
"	Absorbed........	3·51%
Log	O_2 absorbed......	·5453
"	Vol. per min......	·7934
"	O_2 per min.......	·3387 = 218 cc.
"	Weight..........	·6405
"	O_2 per kg. min....	·6982 = 4·99 cc.
(e)		
Log	O_2 per min.......	·3385
"	Cal. value O.. ...	·6913
"	60 min..........	7782
"	Total. Cal. per hr.	·8080 = 64·5 Cal.
"	Surface Area.....	·1523
"	Cal. per sq. m. hr.	·6557 = 45·3 Cal.

Notes:—Samples from Period II. only analyzed.

Analyses.

Sample No. I.		Sample No. II.		
9·176		9.153		Avg. CO_2...... 3·14%
9·175		9.154		" O_2...... 17·57%
				$CO_2 + O_2$...... 20·71%
8.887		8·868		
8.886 = ·289 = 3·10%		8·868 = 1286 = 3·13%		
7278		7263		
7277—1·609 = 17·53%		7260 = 1·608 = 17·61%		
4609	2066	4564	2063	
9628	9628	9614	9614	
4921	2438	4950	2449	

Readings by M. E. A.
Checked by H. M.
Analyses by M. E. A.
Calculations by M. E. A.
Checked by H. M.

These calculations are carried out by four-place logarithms[10] where multiplication or division is required. They are further simplified by a number of computations made in tabular form by various workers, and which can be obtained by those interested. In the last two items (*e* and *f*) the calories per square metre are calculated from the body surface-area which is read at a glance from a height-weight curve published by DuBois[11], and the basal metabolism in terms of percentage of the normal standard from tables of average standards for various sexes and ages published by Gephardt and DuBois[12], and based on numerous observations made by many observers, notably Means[13]. The calculation sheet published on opposite page from one of the periods of the case of polycythemia with splenomegaly reported, will serve as an illustration of how the work is done. On it the calculations are lettered in groups, to correspond to the following key:

(*a*) Volume per min. (in litres) =

$$\frac{\text{log. factor of spirometer} + \text{log. contents of spirometer} + \text{log. correction of barometer and temperature}}{\text{log. time}}$$

$$= \frac{\cdot 1652 + \cdot 5775 + \cdot 9629}{\cdot 9122} = \text{log. of } 6{\cdot}21 \text{ litres.}$$

(The factor of the spirometer is required to reduce the amount of expired air which has been measured in c.m. to litres, and is found by measuring its diameter at three points of its height, and multiplying the square of the average radius by π, and is constant in each spirometer for all experiments. The barometer is corrected to standard pressure and density, by tables at the Smithsonian Institute, and to the temperature of the spirometer by tables made by Miss Sandiford).

(*b*) CO_2 per kg. per min. =

$$\frac{(\text{log. } \%\ CO_2 \text{ produced}) + \text{log. volume per min.}}{\text{log. weight in kilos}}$$

$$= \frac{\cdot 4928 + \cdot 7934}{\cdot 6405} = \text{log. of } 4{\cdot}42 \text{ c.c}$$

(*c*) O_2 per kg. per min. =

$$\frac{\text{log. } \%\ O_2 \text{ absorbed} + \text{log. volume per min.}}{\text{log. weight in kilos}}$$

$$= \frac{\text{log. } \cdot 5453 + \cdot 7934}{\cdot 6405} = \text{log. of } 4{\cdot}99 \text{ cc.}$$

(The oxygen absorbed is obtained by deducting the O_2 expired from the O_2 inspired corrected. The correction for oxygen inspired is obtained from tables by Miss Sandiford based on Haldane's formula, p. 26, "Gas Analysis").

(*d*) Respiratory quotient =

$$\frac{\text{log. } CO_2 \text{ per kilo. per minute}}{\text{log. } O_2 \text{ per kilo. per minute}} = \text{log. of } \cdot 89.$$

(*e*) Calories per square metre per hour =

$$\frac{\text{log. } O_2 \text{ per min.} + \text{log. calorific value } O_2 + \text{log. } 60''}{\text{log. surface area}}$$

$$= \text{log. of } 45 \cdot 3 \text{ calories.}$$

(The calorific value of O_2 for various respiratory quotients is obtained from tables by Williams, Riche and Lusk[14]. The surface area is calculated as above stated from the height-weight curve published by DuBois[11], based on the linear formula.)

(*f*) Basal metabolism in per cent. of normal =

$$\frac{\text{log. Calories per sq. m. per hr.} - \text{log. normal standard for age and sex of patient}}{\text{log. normal standard}}$$

$$= \text{log. of } 28.7\%$$

(The normal standard is taken from the table by Gephardt and DuBois[12].)

III. Observations made on a Case of Polycythemia with Splenomegaly (Osler's or Vaquez's Disease)

So far as is known to the writer, no report has as yet been published upon the basal metabolism of this condition, so that the somewhat scanty observations recorded below are worthy of report, especially as in them, the basal metabolism was found to be raised to a degree that compares closely with the values noted by other workers in pernicious anæmia.

The patient was a man aged fifty-eight in the medical service of Dr. C. F. Martin, to whom I am indebted for the privilege of making and recording this observation. He was admitted to the Royal Victoria Hospital on August 9th, 1916, complaining of flushed appearance, pain in left side, drowsiness, and feeling of fulness in the head, and gave a history of having been "flushed in the face" for thirty years, gastric trouble and splenic enlargement ten years, gastric hæmorrhage six years ago, blood in stools recently. Syphilis denied, but gonorrhœa several times. He was a rather tall man of a very florid high colour, especially in the face and extremities, the scalp, face and hands being of a deep pink and the hands becoming purple when held down. The peripheral venules were distended and the mucous membranes of the mouth and conjunctivæ very red. The spleen was enormously enlarged, reaching to the umbilicus and was tender to pressure and the liver projected below the costal border. The blood count showed 8,400,000 erythrocytes, 21,200 leucocytes, hæmoglobin 110 per cent., moderate anisocytosis, no nucleated reds. The urine was of sp. gr. 1024, acid with a trace of albumen and a few hyaline and granular casts. The blood pressure was not raised, systolic 130, diastolic 80. Pulse, 72–80. Respiration 22-24. Temperature, 98° rose occasionally to 99·2–99·4. The metabolism other than respiratory was fully studied by Dr. E. H. Mason, and is reported upon by him elsewhere. He found the nitrogen values normal. Irradiation with x-ray was done repeatedly. Discharged improved.

The basal metabolism was determined on two occasions, at an interval of five months. The first observation was made on August 23rd, 1916. The experiment was run in two periods, the average of the results showing a heat product of 40·9 *calories per square metre of his body surface per hour*, that is *a rise above the normal standard*, for individuals of his sex and age, *of sixteen per cent.*

The second determination was made on December 13th, 1916, two days before his discharge from hospital. 45·3 *calories per square metre were produced giving a raised basal metabolism of* 28·7 *per cent.* Two periods were run, but samples were only obtained from one. The calculation sheet from this single period is published under the technique (p. 000).

The following summary chart will show the values of interest in both experiments in detail.

ROYAL VICTORIA HOSPITAL

RESPIRATION CHART

SUMMARY OF METABOLISM DETERMINATIONS

Name Thos Dougall Case No. 24405

Age 58 Diagnosis Polycythænia with Splenomegaly.

DATE	WEIGHT	HEIGHT	TEMP.	PULSE	PERIOD NO.	TIME	CO_2 PER MIN.	CO_2 PER KILO PER MIN.	O_2 PER MIN.	O_2 PER KILO. PER MIN.	R Q	VENT. PER MIN. (S.T.P.D.)	HEAT IN CALORIES PER HOURS TOTAL	PER SQ. M.	% NOR.	
Normals:								3.13		3.72	0.84			35.2		
1916	KG.	CM.				A.M.	C. C.	C. C.	C. C.	C. C.		L.	CALS.	CALS.	%	
Aug.23	43.3	162.6	98.0°	69	1	9.02	156	3.60	203	4.69	0.77	7.46				Experiment I
				68	2	9.26	153	3.53	211	4.87	0.73	7.53				
				69			155	3.57	207	4.78	0.75	7.50	58.9	40.9	+16	Average of Periods 1424
Dec.23	43.7	163.1	98.0°	66	II	9.00	193	4.42	218	4.99	.89	6.21	64.5	45.3	+28.7	Experiment II samples obtained from one period only

Remarks. As stated above, the moderately raised basal metabolism of this case of +16 and +27·8 per cent. is very similar to that reported by Means, Aub and DuBois[12], as well as earlier workers, in pernicious anæmia, in which disease a moderately heightened metabolism has been noted in a number of the graver cases. In leukæmia, again, as is well known, the heat production as recorded by many observers[16] is still higher (40–60 per cent.), as also the general metabolism, a fact usually ascribed to the greatly increased white cell regeneration which is proceeding, and which constitutes an embryonic type of tissue. The obscure conditions existing from the metabolic standpoint in pernicious anæmia, in which red cell regeneration is combined with imperfect oxygenation of the muscular tissues of the body as a whole, make the raised heat values in the present case of polycythemia of added interest. For whether the erythrocytosis that is present here be primary or secondary, increased cell regeneration exists.

The subject of true erythræmia or primary polycythemia with cyanosis, with or without splenomegaly, or hypertension, has been reviewed by Lucas[17] in 1912. In connexion with a thorough study of two new cases reported he has collected and tabulated one hundred and seventy-nine from the literature, of which one hundred and forty-nine are undoubtedly genuine. He shows that the disease is now clearly established as a definite and not very infrequent entity. His review of the collected cases throws some side-light on the extremely interesting question of the etiology and the primary or secondary origin of the erythræmia, without, however, leading to any conclusion, as to the causation which still remains in obscurity. Thus in several cases the presence of a caseating hyperplastic tuberculosis of the spleen suggests a compensatory overfunctioning of the bone marrow (primary polycythemia); in others the existence of prolonged stasis suggests a compensatory increase of red cells to carry out the need of oxygenation of the tissues (secondary polycythemia); and in many others, again, the frequent and persistent hemorrhages suggest a vicious circle in which minute quantities of whole blood taken into the circulation act as a stimulus to regenerative bone marrow changes which in turn induce a plethora that is relieved by venesection and hæmorrhage. The action of a toxin causing deoxygenation of the body tissues is another possibility that would lead to a compensatory (secondary) polycythemia. Probably, just as in the pernicious anæmias, we are dealing with a mixed group, from which many cases with a definite etiology can in time be separated from the primary ones.

Summary and Conclusions

1. Through the organization of trained workers and resources, and the researches issuing therefrom, calorimetry has been reduced from an abstract physical science to the province of the well equipped clinical laboratory, and has now an accepted place among the methods of practical application in any large hospital with up-to-date facilities.

2. The basal metabolism of an individual is his heat production in the fasting and resting state, and is here calculated from his linear surface area as derived from the height-weight curve of DuBois, and is expressed in terms of percentage of the normal standard for his age and sex.

3. Clinical calorimetry may be carried out by direct or indirect methods, of which the latter are on the whole simpler and more easily followed by workers with limited assistance and resources.

4. The respiratory-valve and spirometer method of indirect calorimetry, of which the Tissot is the sample and familiar example, gives results that approximate closely, in reliable hands, to those of the direct method, it is simple, and the apparatus easily cared for. The modification installed by us at the Royal Victoria Hospital, Montreal, with the assistance of Dr. Walter M. Boothby, is described in this article and the technique and calculations.

5. Two observations made at an interval of five months are recorded upon a case of polycythemia with splenomegaly. The metabolism was raised on the first occasion 16 per cent., on the second 28·7 per cent.

6. This moderate rise of metabolism compares in an interesting way with cases of pernicious anæmia studied by others in which a similar rise was noted, in view of the red cell regeneration that frequently exists in both diseases.

7. The etiology of Vaquez's disease remains obscure, but the large and carefully studied casuistic, presented by Lucas, supplies the causation in a number of individual cases.

In conclusion, it is my pleasant duty to express my sincere thanks to Dr. Walter M. Boothby and Miss Irene Sandiford for the thorough instruction given me by them in the Tissot method, and for their assistance in this work in many other ways; to Dr. C. F. Martin for access to the clinical material studied, and support of the work; to Miss M. F. Hersey, lady superintendent of the hospital for the coöperation of the nursing staff; to Dr. Louis Gross for the very excellent diagram of the vertical section of the spirometer in use here which he has kindly drawn; and to Mr. E. L. Judah, of the McGill Museum, for much help in adjusting the mechanical part of the apparatus without which it would have been difficult to proceed. I am also deeply indebted to Dr. Thorne M. Carpenter, of the Nutrition Laboratory of Boston, Mass., for giving to both manuscript and proof the benefit of his final revision.

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