A STUDY OF THE BASAL METABOLISM

OF

OKLAHOMA COLLEGE MEN

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PREFACE

Previous experimental evidence (6) has shown that the average basal metabolic rates of Oklahoma college women are consistently below the average normals by the DuBois standards. A study of 101 Oklahoma college women from 17 to 36 years of age gave an average basal metabolism of -13.2%. A later publication (7) gave the tentative conclusion that "prolonged undernutrition is one factor in many of the cases of lowered basal metabolism among Oklahoma college women." The question has arisen as to whether or not Oklahoma men show a correspondingly low basal metabolic rate. This thesis is the report on a basal metabolism study of seventy-five apparently normal, healthy college men.

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INTRODUCTION

1. Historical.

The French chemist Lavoisier is acknowledged as the originator of the science of metabolism which fact makes him also the founder of the relatively new branch of chemistry which we call biochemistry. It has been said of Lavoisier that "this extraordinary pioneer with his combination of originality and clear thinking not only founded a science but established its most important facts as well." (8) He laid the foundation for the science in his discovery of oxygen and the nature of combustion. He showed that the heat of the body is due to the combustion within it, by oxidation, of the carbohydrates, fats, and proteins of which it is composed and which are renewed through the food ingested. He recognized the fact that respiration is the taking in of oxygen to combine with the carbon and hydrogen of these foods and the exhaling of carbon dioxide and water which are formed as the products of the combustion. Lavoisier knew that heat is liberated in this process in much the same manner as in the combustion of the same substances outside the body, and he knew that the body could neither create nor destroy energy showing the correlation between so-called vital energy and other forms of energy.

About the middle of the last century many new facts having to do with metabolism were discovered. It was suggested that analysis of urinary nitrogen would indicate the amount of protein metabolism. Many experiments were made on protein metabolism and protein waste on this principle. For many years physiologists and physicians depended very largely upon data from the analysis of the urine for information regarding the metabolism of matter in the body. Many of these experimentors were seemingly ignorant of the fact that to properly understand the metabolism or transformations of matter and energy in the body a knowledge of both total income and total outgo is indispensable. In many cases, aside from gross estimates of the quantities of food ingested, they made no attempt to determine the income of matter; as to the output, all outlets besides the urine were, as a rule, entirely neglected. Since the disintegration of fats, carbohydrates, and proteins is accompanied by an absorption of oxygen from the air and an elimination of carbon dioxide and H_2O, a thorough knowledge of metabolism must include a knowledge of the oxygen intake and CO_2 and H_2O output of the body. Furthermore, for many purposes the measurement of intake and output of matter must be supplemented by determinations of the transformations of energy since one of the chief functions of food is to supply the body with energy. These determinations cannot be even approximated without the use of apparatus specially constructed for the purpose. For the determinations of income and outgo of energy, which are measured in terms of heat, special forms of apparatus, designated calorimeters were used most extensively by earlier investigators. But a simpler means of making these determinations was evolved after one investigator (21), having carefully determined the fuel values of the foodstuffs, showed by means of a respiration calorimeter that the heat production as calculated from the respiratory exchange is the same as that obtained by the direct measurement of the heat given off by the body. Thus, since the heat given off can be accurately determined indirectly from the oxygen consumption, respiration apparati for this purpose are now more commonly used than the original calorimeters, being much less complicated than these.

II. History of Apparatus

Numerous detailed accounts of various types of respiration apparati have been compiled. Some of these are: Jaquet (15), Tigerstedt (23), Loewy (16), and, more recent, Carpenter (5), and Murlin (19).

Animal calorimetry began when Lavoisier studied the heat given off by an animal body by leaving a guinea pig in an ice chamber for ten hours and observing the amount of ice melted. As early as 1849 the description of a closed-circuit apparatus for the measurement of the oxygen consumption and the carbon dioxide production of animals was published. (20). Since then the development of apparati for measuring the energy metabolism of man has proceeded along two lines. In one type of apparatus the subject is completely enclosed in a chamber; in the other, he is attached to a respiration apparatus by means of some breathing appliance. Both types may be either open-circuit, in which atmospheric air is breathed and expired air collected and analyzed, or closed-circuit, in which oxygen-enriched air is breathed and the consumed oxygen measured. The open-circuit method provides a more complete picture of respiratory exchange since by its use the respiratory quotient may be determined, but the closed-circuit is much simpler technically and quite as satisfactory where only total metabolism must be determined.

There have been numerous variations in the chamber type of respiration calorimeter, but in all cases the apparatus was of necessity quite complicated. In one type the subject was confined in a closed chamber for a period of time (usually several hours). The carbon dioxide content of the air was determined at the beginning and again at the end of the test. The amount of carbon dioxide eliminated during the period was calculated, the volume of the chamber being known.

In a second type the subject was placed in a chamber through which a current of air was passed. The air leaving the chamber was purified by the removal of carbon dioxide and water, replenished with oxygen, and sent back to the chamber. Carbon dioxide, water, and oxygen were all measured.

In yet another modification of the chamber type the subject was placed in a closed chamber through which a current of air was drawn. Both the incoming and outgoing air were analyzed.

Because of the expense of installation and the technical difficulties of operation of respiration calorimeters, heat production is now usually measured indirectly from the gaseous exchange, and the apparatus is of the second general type mentioned above; i.e., in which the subject becomes a part of the closed-circuit, being attached to the apparatus by means of a breathing device. However, calorimeters have provided the means of acquiring most of the present knowledge of energy metabolism and have been extremely valuable in proving the accuracy of indirect calorimetry.

The Benedict-Roth respiration apparatus is a model of this type which is now extensively used in clinics for determining the basal metabolic rate of patients. It is this model which was used in the tests from which the forthcoming data were accumulated, and it will be discussed more in detail later.

III. Basal Metabolism

It was known very early in the study of animal metabolism that there is a certain definite minimum metabolism for an animal body at rest and in the post-absorptive state, which is more or less constant for a species, varying only under certain changes in environmental conditions and in certain diseases of the body itself. This minimum heat production has been designated the "basal metabolism". "It is the amount of energy needed to keep up bodily heat; to keep the heart beating; the muscles used in breathing constantly in activity; and to provide for the tone of such voluntary and involuntary muscles as are in that state of partial activity called tone; in addition, the nervous system in its least form of activity while in a waking state; and the cells of the body in a state of chemical integrity." (17)

IV. Unit of Measurement and Standards.

In 1883 the relationship between the surface area of the body and the heat production was demonstrated (21); thus, a basis for comparison of the metabolism of different individuals was provided. The use of the surface area as the most accurate unit of reference in the study of heat production has been corroborated by numerous later investigators in the field (8) and (18). However, there has been some opposition to this use of the surface area (3) and (22).

In 1915 DuBois devised the most satisfactory method for estimating the surface area of the body (9) and later published normal standards of heat production for males and females, the accuracy of which has been fairly well established.

V. Value of Basal Metabolism Determinations.

A knowledge of the normal basal metabolic rate is of fundamental importance to the biochemist in that it gives him a starting point from which to proceed in his investigations. For the physician it holds a special meaning for he can apply it in the diagnosis of certain diseases which have been found to raise or lower this basal metabolic rate. It has been shown repeatedly that the great percent of normal individuals (99.3%) (4) have a basal metabolic rate within 15% of the DuBois standards. In many clinical cases, however, the basal metabolism is well outside this zone. Of these diseases probably the most widely discussed in connection with basal metabolism studies are those associated with malfunction of the thyroid glands. Likewise, from the metabolic standpoint the most important thyroid disease is exophthalmic goiter, sometimes called hyperthyroidism. This disease is characterized by a marked increase in the basal metabolic rate. Myxedema, a thyroid disease in which thyroxin is diminished, tends to lower the basal metabolism -- sometimes as much as 40%. In this disease determination of the basal metabolism is used in connection with treatment as well as diagnosis for it serves as a valuable means of controlling doses in the therapeutic administration of thyroxin. In short, all conditions in which there is an increase in the flow of thyroxin tend to raise the basal metabolic rate and those in which this flow is diminished decrease it.

Among the diseases or conditions known to cause an increased basal metabolism are the leucemias, Graves' disease, erythremia, dyspnea, and fevers. The anemias tend to lower it.

The clinical significance of the basal metabolism is, of course, its chief value, but those who have worked most with it caution against a slavish adherence to the test as an index of diagnosis.

DuBois (10) has suggested another application for a knowledge of the basal metabolism. He says that it is only through a study of the factors which influence basal metabolism in health and disease that dietetics can be placed on a scientific basis. This is especially true of hospital dietetics.

VI. Factors Influencing the Basal Metabolism.

There are numerous factors other than disease which affect the basal metabolism. Among the purely environmental are season and climate. The basal metabolism tends to be at a low level in the winter and to rise to a higher level in the spring and summer (13). Internal conditions, however, are more important in the regulation of metabolism. Basal metabolism seems to be influenced by the ratio of inert body fat to active protoplasmic tissue existing in the body. All other factors being equal, the basal metabolic rate probably varies directly with the proportion of active protoplasmic tissue (3). This is indicated by a number of facts, namely: the basal metabolism of athletes is greater than that of non-athletes of the same height and weight (1 and 25); the basal metabolism is higher for men than for women of the same height and weight (2). Certain factors influence the basal metabolic rate temporarily and thus may give a false test. An hour of severe muscular work causes a slight increase in basal metabolism the following day (24). A high protein diet will markedly increase the rate the day after its ingestion (24). These latter factors may be classed as stimulation to cellular activity. Included here also are such factors as age, drugs, and internal secretions. A factor which influences the basal metabolism to a varying degree and one which should be most avoided by technicians is emotional disturbance. Grafe and his associates (11 and 12) have shown the effect of emotion upon basal metabolism by means of hypnosis. They made a series of experiments on young normal men and women suggesting to them, while under hypnosis, the most terrible calamities. In the majority of cases there was an increase in basal metabolism ranging from 5 to 25 percent, the average for the whole series being 7.6%. There is much controversy as to the effect of mental activity alone upon metabolism but it is probably most widely believed to have little effect.

Benedict (3) has summed up these factors which influence the basal metabolism stating that the basal metabolism of an individual is a function, first, of the total mass of active protoplasmic tissue and, second, of the stimulus to cellular activity existing at the time the measurement of metabolism is made.

EXPERIMENTAL

Subjects.

Previous experimental evidence (6) has shown that the average basal metabolic rates of Oklahoma college women are consistently below the average normals by the DuBois standards. A study of 101 Oklahoma college women from 17 to 36 years of age gave an average basal metabolism of -13.2%. A later publication (7) gave the tentative conclusion that "prolonged undernutrition is one factor in many of the cases of lowered basal metabolism among Oklahoma college women". The question has arisen as to whether or not Oklahoma men show a correspondingly low basal metabolic rate. This thesis is the report on a basal metabolism study of seventy-five apparently normal, healthy college men. The tests were run in the fall semesters of the school years 1935-36 and 1936-37. The subjects were chosen indiscriminantly and varied in age from 17 to 30 years, the majority falling within the range of 18 to 24. All tests were, of course, run under the necessary basal conditions.

Apparatus.

The apparatus used for the tests in this project is the standard Benedict-Roth recording metabolism apparatus with the Collins kymograph. This model is a modification of the original Benedict portable. Roth's modification consists

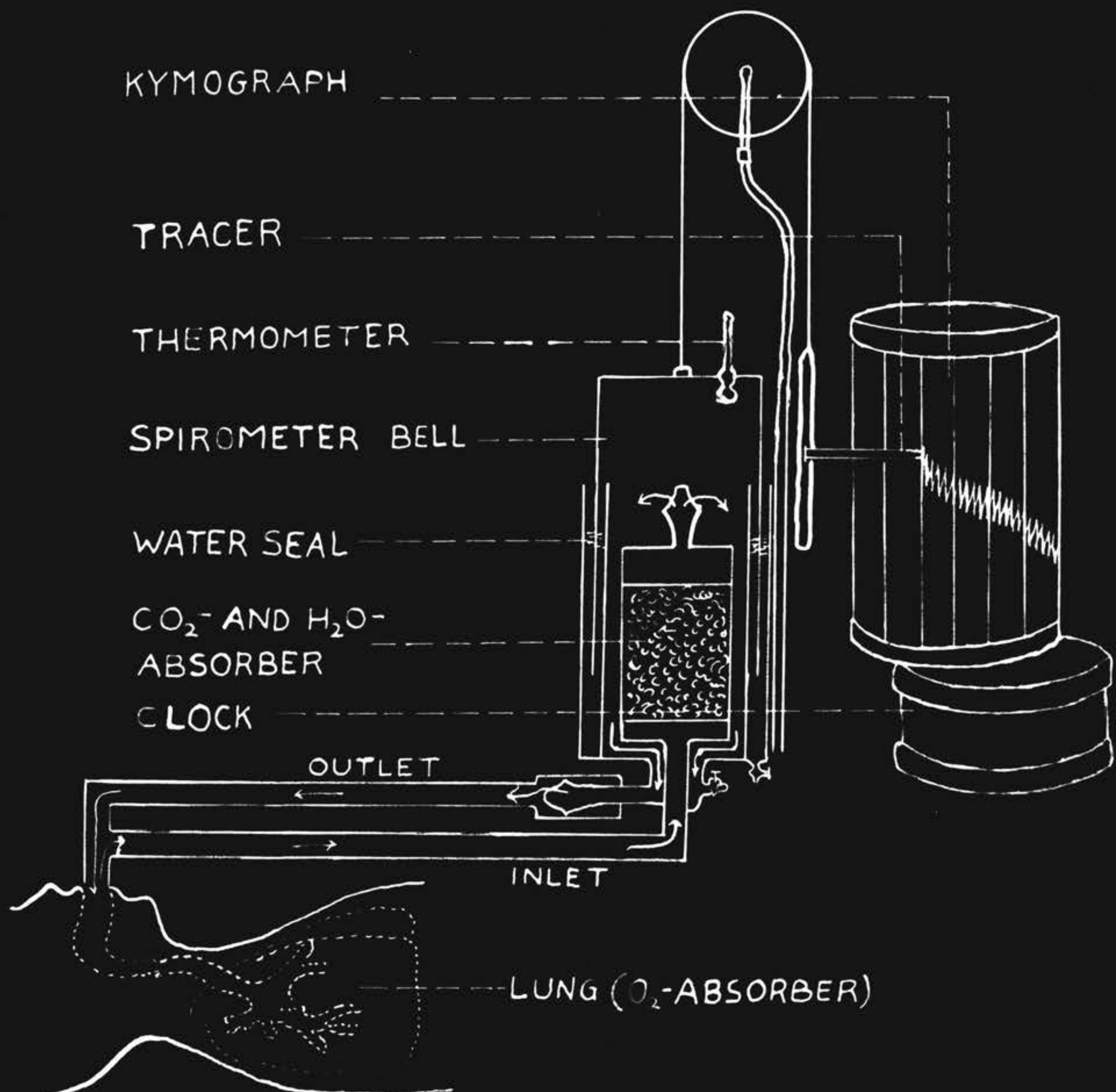


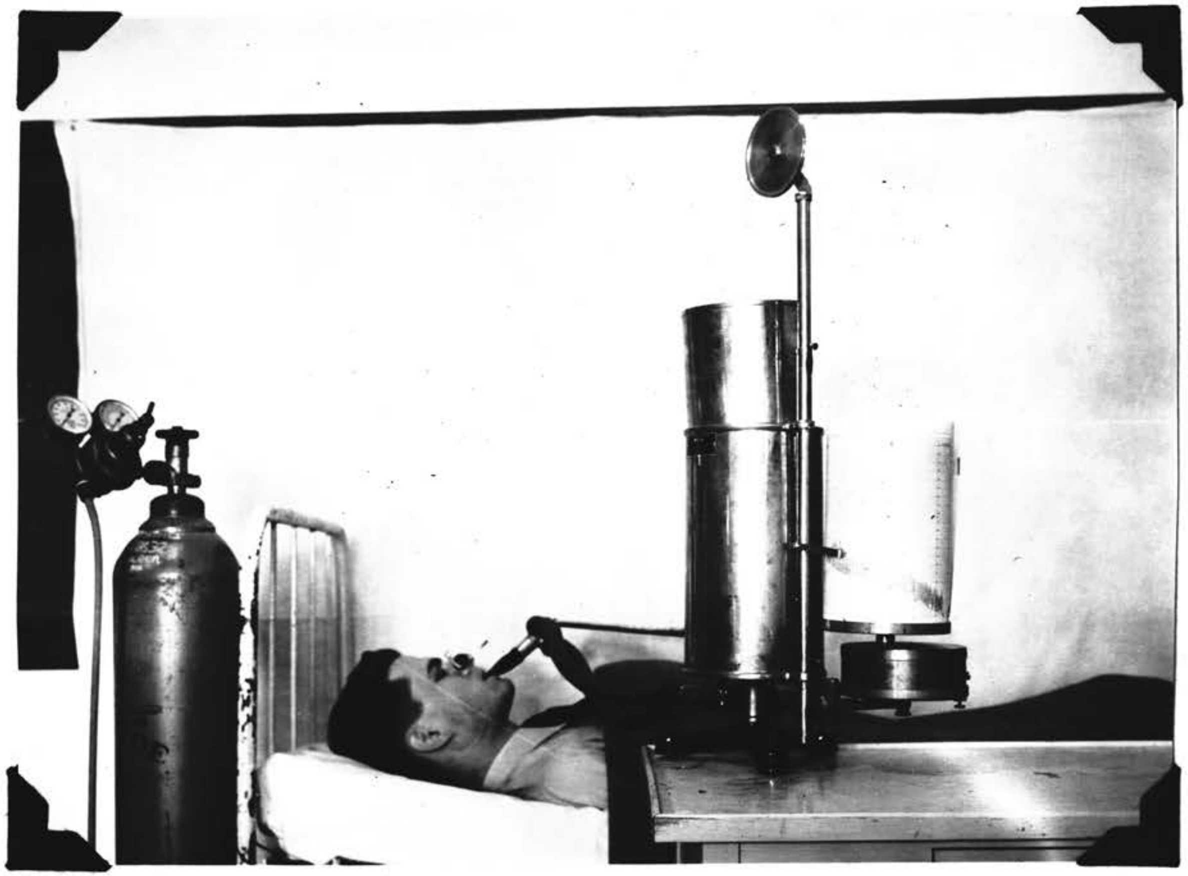
FIG. I. DIAGRAM OF THE BENEDICT-ROTH RESPIRATION PPARATUS, SHOWING THE ENTIRE CLOSED AIR-IRCUIT. (ADAPTED FROM ROTH.)

chiefly of the substitution of flutter-valves to control the passage of air in the circuit for the electric air impeller that was used originally. Figure 1 shows diagrammatically the entire circuit with use of this apparatus and the photograph on page 12 shows it in operation. During the course of the study the apparatus was tested regularly for leaks, and the soda lime for carbon dioxide absorption was changed often.

Calculations.

The basal metabolic rate is expressed in percent above or below the normal standard (in this case the DuBois standards). The calculation of this rate has been reduced to simplicity by the convenient tables which appear on the back of the graph paper prepared especially for use with the Benedict-Roth equipment.

Any six-minute rise of the "oxygen-consumption line" is the measure of the fall of the spirometer bell (see Figure 1) for the same length of time. The bell has a standard capacity of 20.73 ml. per mm. of height. This amount of oxygen at the average calorific value of 4.825 calories per liter equals .1 calory. Therefore, 1 mm. rise of the oxygen line on the graph in six minutes represents 1 calory per hour, subject to standard correction for temperature and pressure. This correction is made by use of a table of correction



Benedict-Roth Apparatus
In Operation

factors made up especially for use in metabolic rate calculations when oxygen-consumption is measured by means of the Benedict type of respiration apparatus. This table is made to cover a range of temperatures by degrees, from 15° to 35°C. and barometric pressures for every 5 mm. from 600 mm. to 780 mm.

The corrected calories-per-hour value thus obtained is compared with the standard normal for individuals of the same sex and age of the patient. This standard is derived from a table supplying calories per square meter per hour for age groups of each sex. As the actual test gives the total number of calories per hour this standard value must be multiplied by the body surface area of the patient before the two values can be compared. The DuBois body surface chart, a nomograph prepared by Boothby and Sandiford of the Mayo Clinic, makes it possible to determine this body surface area rapidly and sufficiently accurately from the height and weight of the subject.

The difference between these two values is divided by the normal value thus converting it to percent of the normal, and this is reported, being labeled plus or minus, depending upon whether the value obtained from the actual test is greater or less than the normal.

Table A

Age			No.	Mean Wt. in Kg.	Mean Surf. area (Sq.M)	Mean total heat production (Cal. per 24 hrs.)	Mean Cal /Kg per 24 hrs.	Mean Cal/ Sq.M per 24 hrs.	Mean Cal /Sq. M. per hour	Mean Basal Metabolic Rate
17	19	18	27	65.75	1.79	1762.9	26.8	984.8	41.03	-4.42%
20	24	22	39	72.14	1.91	1761.3	24.41	922.1	38.4	-6.34%
25	29	27	9	72.6	1.87	1696.8	23.37	907.4	37.8	-6.2%

Results.

Table A is a summary of all data accumulated from the seventy-five tests run. The subjects were assembled into age groups as indicated for convenience in handling, and because the number of subjects of each age studied was not large enough to give reliable results if considered alone.

Data from the studies of Harris and Benedict (14) show little difference from the above data in mean total heat production for similar age groups. The following table gives their results in a metabolism study of men of the ages indicated:

Table B.

Age		No.	Mean Total Heat Prod.	Mean Heat Per Kg.	Mean Heat Per Sq. M.
15-19	17	11	1753	26.95	968.4
20-24	22	59	1676	25.10	946.2
25-29	27	33	1590	25.90	919.6

It will be noted that in all three age groups the difference in total calories is in favor of the Oklahoma men. But a consideration of the two tables show that even though the above is true, the mean heat per kilogram for Oklahoma men is the lower in all three age groups, and the mean heat per square meter is lower for two out of the three groups. This would indicate, of course, that the Oklahoma subjects were of larger average stature than Benedict's subjects.

Table A indicates the lowered basal metabolic rate

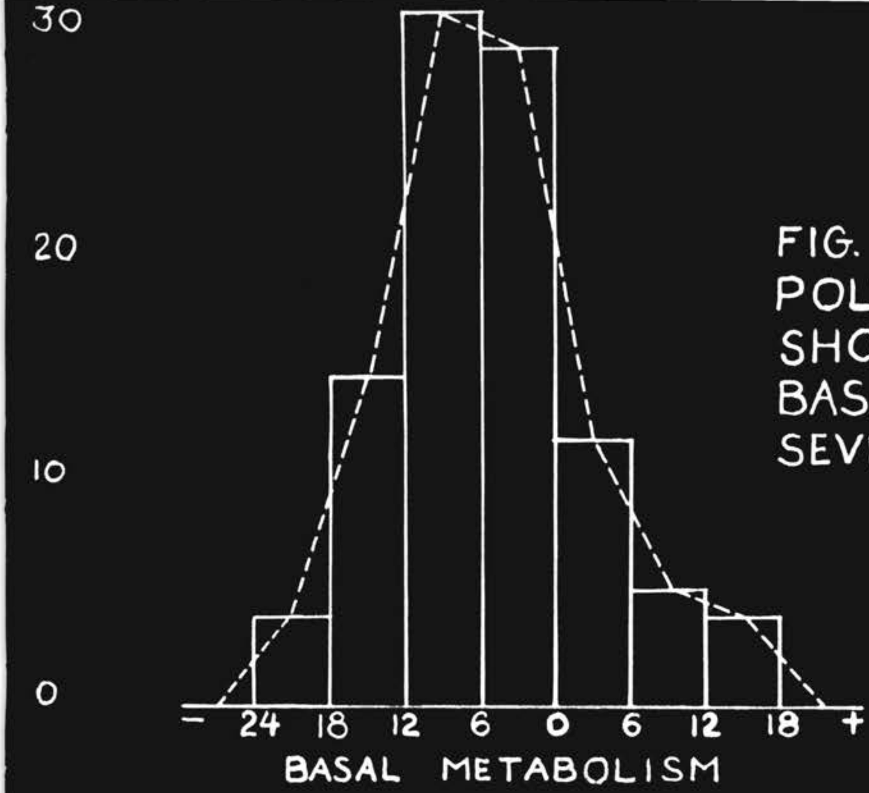


FIG. 2. FREQUENCY-POLYGON AND CURVE SHOWING VARIATION IN BASAL METABOLISM OF SEVENTY-FIVE COLLEGE MEN.

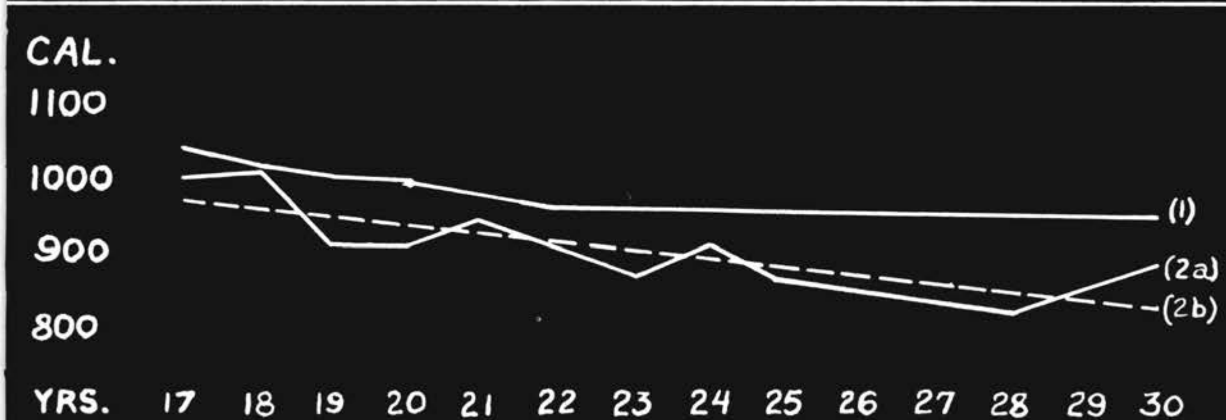


FIG 3. TOTAL HEAT PRODUCTION PER SQUARE METER OF BODY SURFACE REFERRED TO AGE.

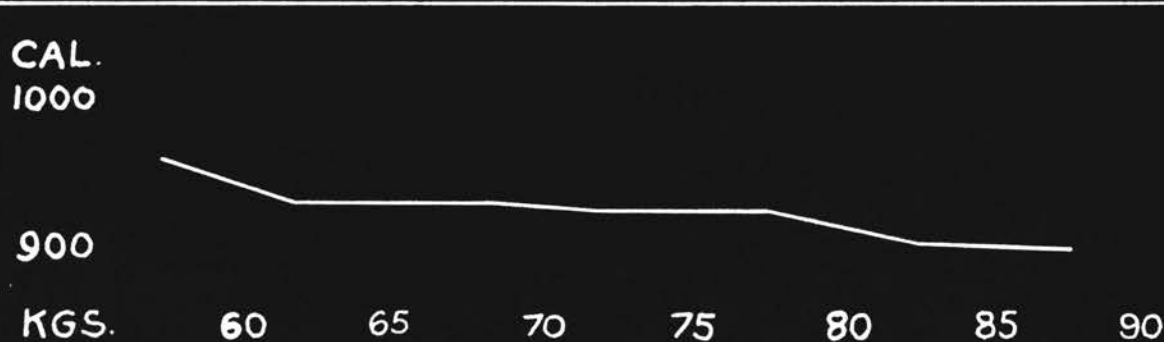


FIG 4. TOTAL HEAT PRODUCTION PER SQUARE METER OF BODY SURFACE REFERRED TO WEIGHT.

shown by Oklahoma college men. The average basal metabolism for all age groups was found to be -5.63%. Of all subjects studied 76.4% fell within the range of ±10% of the DuBois normal; 21.9% fell below -10%; and 8.2% were below -15%.

Figure 2 represents graphically the distribution of the basal metabolic rates of all the subjects over the range from -24% to +18%. The fact that the mode is in the range from -6 to -12 would lead one to believe that the average basal metabolism of the entire group would be somewhere in that range rather than the calculated -5.63%, but the close approximation of the 0 to -6 frequency to that of the mode along with the skewness of the variation curve to the right accounts for this. The variation curve approaches rather well the normal curve considering that the number of individuals was not exceedingly great.

Figure 3 shows the gradual decline of the heat production per square meter of body surface, with increasing age. Line 1 was plotted from the normal DuBois standards. Line 2a was plotted from data assembled in this study, and line 2b is the slope of 2a calculated by the method of least squares. 2b shows a steeper decline than does 1. I see no reason for this peculiarity.

Figure 4 indicates that within the weight range of the great average the basal metabolism is not influenced by body weight, at both extremes in weight the slope of the line is greater. That is, total heat production referred to square meter of body surface seems to increase more rapidly as the subjects become very light and to decrease rather more rapidly as they become very heavy, than it does over the intermediate range.

SUMMARY

1. A comparison of the data compiled in this study for Oklahoma men, with that for a similar study made by Harris and Benedict (14) shows, that the mean total head production is greater for the Oklahoma men in all age groups, but the mean heat per square meter of body surface area and, thus, the basal metabolic rates are less than for the Harris-Benedict subjects.

2. Oklahoma college men show low basal metabolic rates by the DuBois standards, the average rate for all subjects studied being -5.63%.

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