THE BASAL METABOLISM OF TWENTY-FIVE KANSAS GIRLS BETWEEN SIXTEEN AND EIGHTEEN YEARS OF AGE

by

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INTRODUCTION

Establishment of standards for predicting basal metabolic rates has been of necessity a slow process because many factors modify the findings. More acceptable standards should be established by the acquirement of measurements on large groups and by a more thorough study of changes in metabolism in relation to these influencing factors, one of which is age.

"The term metabolism is used broadly for all the chemical changes which take place within the body under the influence of living cells." (24) In these changes, oxygen is consumed and ultimately energy in the form of heat is produced. The amount of heat thus formed is a direct measure and the amount of oxygen absorbed is an indirect measure of the metabolism of the subject. Muscular activity and the ingestion of food increase the processes of combustion within the body, whereas complete rest and the postabsorptive state reduce them to a minimum which is known as basal metabolism. For practical purposes, this minimum rate of metabolic activity is determined after at least 8 hours of sleep or rest in bed, and 12 to 18 hours after the last meal. The subject is awake and lying physically and mentally relaxed in a room comfortably warm. In each case the body temperature is normal.

While basal metabolism is fairly constant in a given individual, such factors as size, age, and sex influence it greatly. Body build and size quite obviously have an effect on heat production, but metabolism is fairly proportional to surface area when both height and weight are considered. Women have been found to have a lower basal metabolism than men and in both sexes there is a decrease in the level with advancing years. There is some indication that the menstrual cycle and the menopause affect the metabolic rate of women. Highly active, muscular individuals show results slightly above average while inactive ones of similar size and shape tend to be low. It is evident that sleep causes a marked drop in metabolism and some workers believe that a true basal condition is found only at this time. Several conflicting beliefs exist concerning the effect on metabolism of external temperature, altitude, climate, season, and race. However, there are not enough convincing experiments as yet to warrant any definite conclusions as to the influence of these factors.

REVIEW OF LITERATURE

The foundation of the present knowledge of metabolism is based on the scientific observations of Sanctorius in 1614 (8). From his experiments, he discovered evidence of gaseous emanations from the body, arising from the lungs in exhalation and from the skin by vaporization, and known as insensible perspiration. Lavoisier and LaPlace in 1780 (20) discovered that during respiration oxygen is used and carbon dioxide is produced. They demonstrated increases in heat production caused by exposure to cold, by taking of food, and by exercise. In 1850, Regnault and Reiset (16) presented the principle of a closed-circuit respiration apparatus. The following year Bidder and Schmidt (20) defined basal metabolism, stressing the influence of age, sex, individuality, body volume, body surface, and environmental temperature.

Pettenkofer in 1862 (20) built a respiration chamber large enough for the study of human subjects, and with this apparatus Voit and Pettenkofer established our modern conceptions of the metabolism of man. In 1905 Zuntz and Geppert (20) constructed a portable open-circuit respiration apparatus, capable of measuring the oxygen consumption and carbon dioxide production during short intervals. Zuntz realized the importance of complete muscular repose in determining the basal metabolism of human subjects. In 1897, (20) Atwater and Rosa devised an extremely accurate apparatus known as a respiration calorimeter which measured the water and carbon dioxide output and determined the heat given off by the body, by recording the rise in temperature of a known amount of water as it flowed through a system of pipes in the calorimeter. At the suggestion of Benedict, the closed-circuit principle of Regnault and Reiset was applied to the Atwater-Rosa machine so that the same air was used over and over again and the oxygen consumption measured directly.

In 1883 Rubner (8) contributed his formulation of the "Law of Surface Area." Regardless of size and species of animal, the amount of heat produced per unit of body surface is approximately the same, according to Rubner's law. DuBois (8) presented an accurate method for measuring the actual surface area of the body. From a series of these measurements he devised a height-weight formula and, to avoid calculation, constructed a chart so the surface area could be determined with greater facility. He also established normal standards for basal metabolism for different ages and for both men and women. These standards have been modified by Boothby and Sandiford (8) and are now used by many workers to determine whether the metabolism of the individual under investigation is normal.

Lusk and Benedict (20) have been undoubtedly the two most significant early American workers contributing to the science of energy metabolism. Lusk devoted most of his study to metabolism in disease and to the effects of food on heat production. Benedict has made his principal consideration the study of normal controls and the standardization and use of metabolism apparatus.

At the present time standard tables for basal metabolic rates have been established by Harris-Benedict (1919), Aub-DuBois (1917), Dreyer (1921), and others. These tables are now used for comparing metabolic work carried on throughout the country.

Blunt, et al. (5) reported high results according to Benedict's standards from their study of the basal metabolism of girls between the ages of nine and thirteen. They emphasized the influence of variations in build on basal metabolism. Underweight girls showed a high basal metabolism if computed in calories per kilogram. In terms of total calories, calories per square meter, or calories per centimeter, the results were low or normal. The basal metabolism of overweight girls was low if computed in calories per kilogram and high if computed in calories per centimeter or total calories. Comparisons made on the basis of calories per square meter seemed to show the least variation from the average, regardless of build. Lucas and Pryor (15) reported that slender-built children had higher basal metabolic rates than broad-built children of the same age-sex group. The difference in the relative width of the body seemed to be the determining factor in oxygen absorption both in total amount and on a per unit basis of weight and body surface. Molitch (21) made observations contrary to those of Lucas and Pryor (15). In a series of basal metabolic studies on boys he found no correlations between body build and oxygen consumption. A high basal metabolic rate was not characteristic of the linear type of build according to this worker. McKay (17) reported, from observations on young women, that heat production per kilogram decreased quite decidedly with increased weight. Overweight girls averaged 9 per cent less and underweight girls averaged 12 per cent more per kilogram than the mean for the entire group.

Tilt (29) found the basal metabolism of young college women in Florida to be -9.9 per cent of the Harris-Benedict predictions and -10.6 per cent of those of Aub and DuBois. The age range of these young women was from 17 to 25 years. Studies of the metabolism of young women in Oklahoma were made by Coons (6). The ages ranged from 17 to 36 years. The results showed an average deviation of 13.2 per cent below the DuBois predictions and 10.1 per cent below the Harris-Benedict and Dreyer standards. McKittrick (19) observed that the deviations calculated on basal metabolic rates of Wyoming University women from 17 to 26 years of age were -3.18 per cent and -2.54 per cent of the predicted standards of Aub-DuBois and Harris-Benedict, respectively. Comparisons with the Oklahoma and Florida studies indicated that the higher altitude of Wyoming raised the basal metabolism almost 10 per cent.

Studies of the influence of season on basal metabolism have given contrary results. Benedict and Carpenter (3) stated that the basal metabolism on any one day remained singularly constant from hour to hour. Benedict (2) also performed experiments on himself and concluded that the basal metabolic rate remained uniform from day to day. When subjects were observed from month to month, seasonal differences in metabolism were evident. However, no definite conclusions could be made for any particular season, as the results of some workers were high during winter and low during summer while others found the relation to be reversed. According to Osborne (24) the high level of metabolism in the summer was due to increase in body temperature which is produced by any kind of exertion during the hot season. Corlette (7) explained that during cold weather more heat is produced to keep the body warm so metabolism is high.

Lockwood and Griffith (14) demonstrated seasonal and menstrual variations in basal oxygen utilization under conditions of controlled temperature, humidity, and diet. The total seasonal variation of approximately 3.5 per cent showed the low part of the curve in the fall and the high in the spring. Menstrual variation amounted to about 6 per cent with its lowest mean value at the eighth day of the cycle and the highest point just before the onset of menstruation.

A fall in basal metabolic rate with submaintenance diets was reported by Benedict, et al. (4) but the effect of the kind and quantity of food was questionable. Studies in New Orleans, made by Hafkesbring and Borgstrum (9), indicated that the kind and quantity of food eaten influenced the basal metabolism. However, no specific diet was followed by these subjects. Talbot (28) noted that a liberal diet tended to increase basal metabolism and a restricted diet decreased it. Hetler (10) observed protein intake and basal metabolism of 85 Illinois women with the majority within 19 to 24 years of age. No definite inter-relationship could be noted between protein intake and the basal metabolic rate but it was suggested that the lower protein intake of women may be responsible for the fact that women's basal rate is usually lower than that of men. Tilt and Walters (30) studied the basal metabolism of 30 young women between the ages of 17 and 26 years in Florida and found no significant seasonal variation and no consistent relationship between basal heat production and protein or calorie intake. Relationship of dietary intake and basal metabolism was considered in the metabolic studies of Johnston and Maroney (11). They concluded from their results on 33 Detroit children that a high caloric and high protein intake caused a maximal elevation of the basal metabolic rate. There was also a slight increase noted upon the addition to the adequate diet of a plethora of carbohydrate and with a plethora of fat.

It is generally believed that the heat production per unit of weight of the new-born is lower than that of adults but a sharp rise is evident during the first year of life until at the end of the year the rate exceeds that of the adult. DuBois and co-workers in 1914-1915 (8) noted that heat production was higher than expected about the time of puberty and that it fell after this period. Talbot (28) was unable to find this rise in all of the subjects included in his study in Boston. Nalbandov, et al. (22) observed that the basal metabolic rate of Oklahoma children was lower as their age increased than that of northern children. The decrease was most marked in the group of girls at puberty. In the very young children the measurements agreed with the northern results. Since the basal metabolic rate is thought to be a function of the active protoplasmic tissue the rapid growth of these children may have caused the higher heat production. Lewis (12) made a study on the curves of growth and basal metabolism of 39 post-pubescent New York girls from 14 to 16 years of age at the Hebrew Orphan Asylum. With chronological age a consistent decrease in basal metabolism was evident. However, there was no indication of any relationship between physiological age and basal metabolism or rate of growth and basal metabolism. McKay's (17) Ohio study on young women gave evidence of a decrease in basal metabolism from 14 to 18 years of age.

The rate of basal metabolism throughout adult life is generally believed to be characterized by a gradual decline followed by a more pronounced drop in old age. There have been only a few experiments on adults over 50 years of age. McKay and Patton (18) obtained data on women 35 to 70 years old. They concluded from their results that the heat production of women remains at a fairly uniform level until the age of 50 or thereabouts, after which the basal metabolism declines to a definitely lower level. Lewis (13) observed change with age in the basal metabolic rate of men from 40 to 90 years of age. The decline after 40 was very gradual and might be almost arrested between 50 and 80 years, after which a more pronounced decline was evident.

Although measurement of respiratory exchange remains the accepted procedure for the determination of energy metabolism, recent investigations have suggested the possibility of using creatinine excretion as an equally reliable index. Takahira (27) observed that the creatinine nitrogen output in the urine was somewhat proportional to the body weight and basal metabolism. Stark (27) and Talbot (28) demonstrated a close relationship between creatinine excretion and basal metabolism. Wang (31) made a study of a group of 70 children, the results of which varied considerably from those of Talbot. The basal metabolic rate and the preformed creatinine did not run parallel at all ages for this group of children. The ratio between the two was not constant. She suggested that some other factor or factors aside from active protoplasmic tissue may be responsible for the production of either basal heat or creatinine or of both. More study will be necessary before the level of the urinary creatinine can safely be employed as a basis for evaluating basal metabolism and used as a means of predicting basal heat production.

PURPOSE

A study of basal metabolism is being made on Kansas State College women between 18 and 25 years of age as part of a regional cooperative project. Of the numerous studies made on the basal energy requirements of young women, only a small minority have included subjects below 18 years. Therefore, it was deemed desirable to contribute information which, when supplemented with more subjects, will provide a standard for girls of this age and a basis for comparison of the basal metabolism of young girls with that of young women. The present study concerns the basal metabolic rate of young girls from 16 to 18 years of age and a comparison with the findings of other investigators of this age range.

PROCEDURE

A 1935 Benedict-Roth closed-circuit respiration apparatus, illustrated in Fig. 1 was used for the tests. The spirometer chamber was filled with oxygen which the subject inhaled through a rubber mouthpiece. The exhaled air was transmitted through a container of soda lime to insure complete absorption of the carbon dioxide. The soda lime was checked after each test by discharging the residual gas from the spirometer chamber into a solution of barium hydroxide. If a precipitate clouded the solution, carbon dioxide had accumulated and a fresh supply of soda lime was necessary. Respiration recordings were made on the kymograph by means of the pen connected with the spirometer bell.

During each test, the apparatus was tested for leaks by placing a ten-gram weight on the spirometer bell in the middle-two minutes of each eight-minute period. The presence of a leak would cause a rise in the slope of the respiration tracings on the chart due to the escape of oxygen as a result of the added weight. Leaks may occur around the mouthpiece if the lips do not fit closely about it, the nose clamp may not be tight enough, the rubber tubings may leak at their connections to the apparatus, or the stop cocks may not be entirely closed.

The subjects were senior and junior girl students of the high school of Manhattan, Kansas. The majority of them planned to enter Kansas State College following graduation from high school so further study may be conveniently made at a later age if desirable. Their physical condition was deemed normal as far as could be determined by observation and questioning. The students were notified in time to make the necessary preparation for the test. The subject was instructed to secure at least 8 hours of sleep or rest in bed the night before the test was given, to take no food after the evening meal, and to eat nothing in the morning. The water intake was not restricted. After arising from bed and dressing with a minimum of physical exertion, the subject was brought to the laboratory in a taxicab. In the case of any excitement prior to the test, no observation was made. No tests were given during the menstrual period nor for four or five days before and after the period. As duplicate determinations were desired, appointments for two mornings were made as close together as possible to insure stability of the subjects' physical condition. Two eight-minute periods were measured on each of the two mornings and the best six consecutive minutes were used in each of the four tests.

On the morning of a test, the apparatus was prepared and the room temperature made comfortable. The subject rested on a bed for a period of 30 minutes after reaching the laboratory. Before the test was given, the temperature and pulse of the subject were recorded. The spirometer temperature was recorded before the subject was connected to the apparatus and again at the end of an eight-minute respiration record. After the subject had rested a few minutes the test was repeated. Following the second determination the height and weight of the subject and the barometric pressure of the room were recorded.

From the slope of the curves and the calibration of the spirometer it was possible to determine the number of cc. of oxygen consumed in each six-minute period. Since the spirometer bell contained 20.73 cc. of oxygen per mm. of its height, one mm. fall of the bell in six minutes was equivalent to 20.73 cc. of oxygen or 207.3 cc. of oxygen per hour.

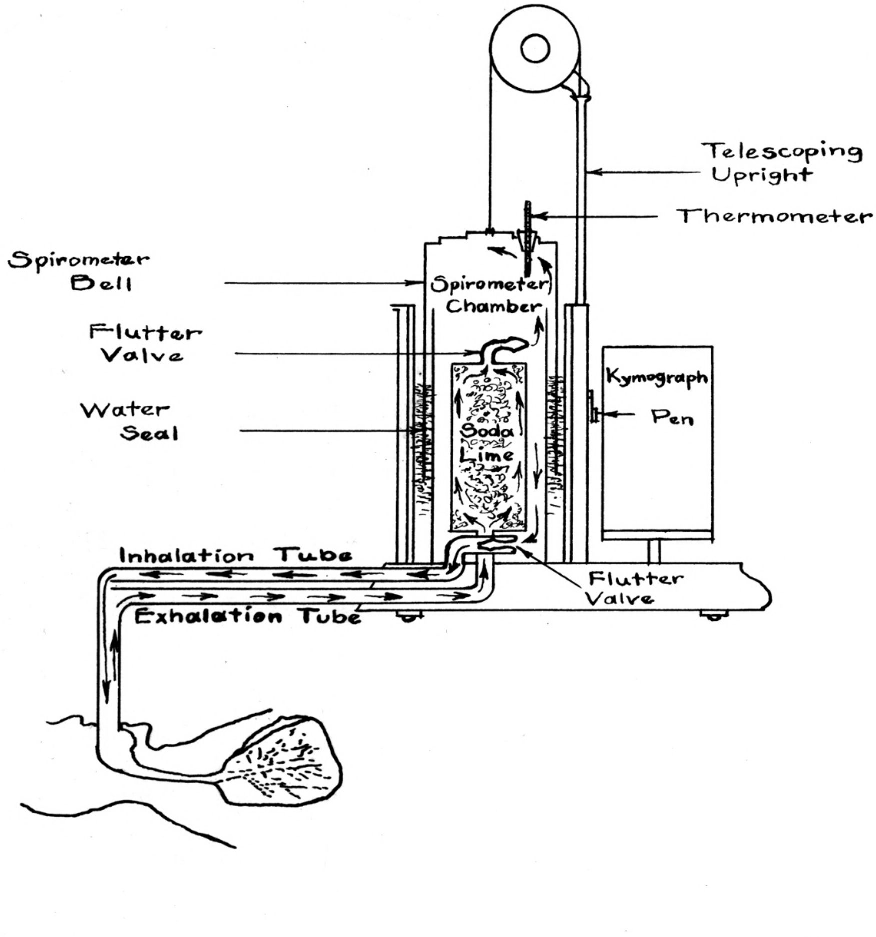

Fig. 1. Principle of the recording spirometer. (Benedict-Roth principle) (8)

The heat equivalent of one liter of oxygen is 4.825 Calories. 207.3 cc. of oxygen are equal to 0.2073 liters of oxygen and when multiplied by 4.825 Calories are equivalent to one Calorie per hour. Therefore, the number of mm. of oxygen used in six minutes (after the volume was corrected for spirometer temperature and barometric pressure) was assumed to be the measure of Calories burned per hour.

DISCUSSION OF RESULTS

The results concerning the heat production of 25 Kansas girls between 16 and 18 years of age are shown in Table 1. These were computed on the basis of age, weight, height, surface area, total Calories per 24 hours, Calories per kilogram per 24 hours, Calories per centimeter per 24 hours, Calories per square meter per hour and the percentage deviation from the Aub-DuBois (1917) standards as modified by Boothby and Sandiford.

The mean basal metabolic rate of this group of girls between 16 and 18 years of age was 34.59 Calories per square meter per hour. This is approximately the same as the findings of Shinkle (26), who reported the basal metabolic rate of 54 freshman Kansas women, most of whom ranged from 17 to 23 years of age. Her results showed the mean Calories per

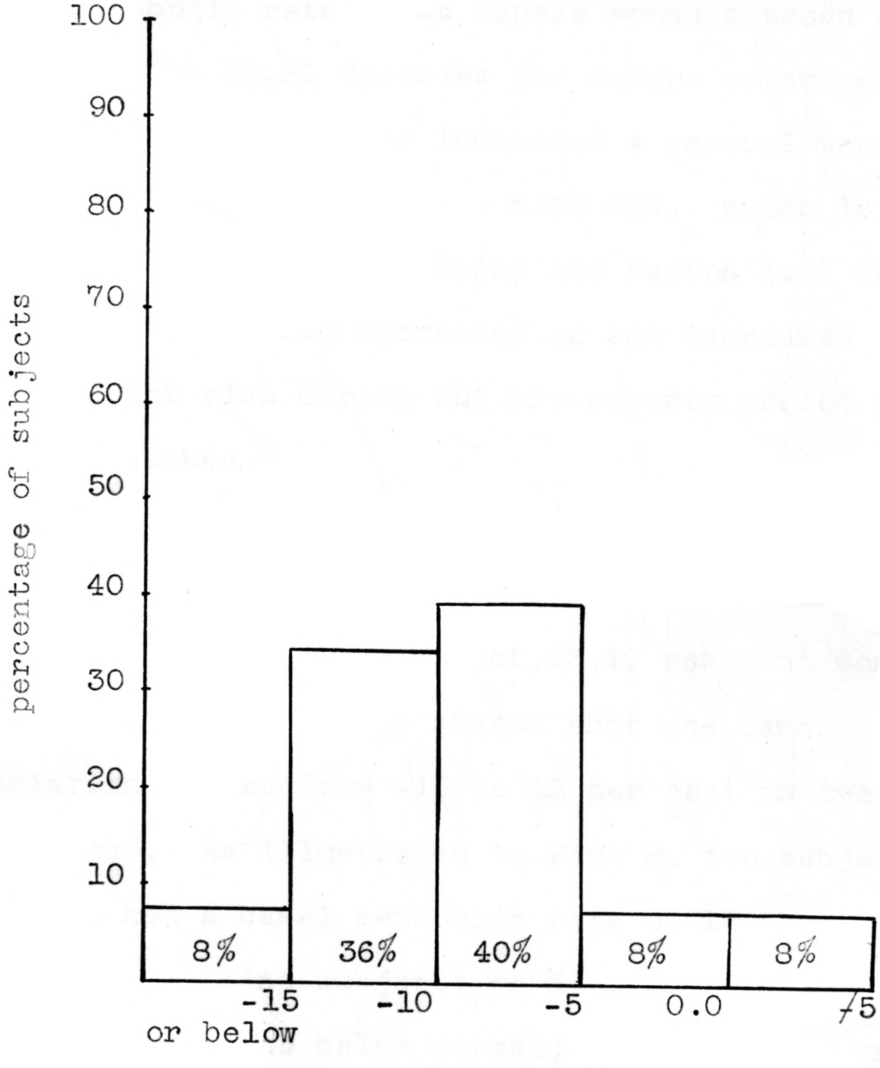

Fig. 2. Percentages of twenty-five subjects above or below the modified Aub-DuBois normal standard.

square meter per hour to be 34.87. Richardson (25) reported the mean basal metabolic rate of 25 Kansas women between 25 and 30 years of age as 32.21 Calories per square meter per hour. These three investigations indicated a general tendency of basal metabolism to decrease with age, which is consistent with the conclusion of McKay and Patton (19) who stated that "basal metabolism decreases as age increases with perhaps a slight rise during the pre-puberty period until adulthood is reached."

The lowest individual basal rate obtained was -17.82 per cent deviation from the modified Aub-DuBois standard and the highest was 7.37, making a range of 25.19 per cent for all of the subjects. Talbot (28) stated that the usual amount of variation ranges from -15 to 15 per cent in the 8-18 year age group. As illustrated in Fig. 2, two subjects or eight per cent had a basal metabolic rate of 15 per cent or more below normal; nine subjects or 36 per cent, a rate between 15 and 10 per cent below normal; ten subjects or 40 per cent, a rate between 10 and 5 per cent below normal; two subjects or eight per cent, a rate between 5 per cent below normal and 0.0 per cent; two subjects or eight per cent, a rate of 0.0 per cent or above normal. The fact that the results of the present study fell considerably lower than the standards in common use is consistent with the findings of Tilt (29) and Coons (6) previously discussed in the Review of Literature and gives further indication that these standards may be too high.

A cooperative regional five-year study on basal metabolism of college women between 18 and 25 years of age is now in progress at Kansas State College and in four other states. A period of four years has been completed. Richardson's (25) study on women from 25 to 30 years and the present study on girls from 16 to 18 years of age made it possible to combine the results of these three investigations and calculate the mean Calories per square meter per hour for each age group between 16 and 30. Table 2 indicates a probable general tendency of the mean Calories per square meter per hour to decrease as age increases.

The cooperative regional study in progress includes five states: Minnesota, Ohio, Iowa, Oklahoma, and Kansas. Comparison of the mean results from these states, expressed in Calories per square meter per hour for the 16- and 17-year age groups, Table 3, shows much similarity.

A comparison of the basal metabolism of the 16-17 year age level is made between this study and studies of other workers, as shown in Table 4. Benedict's (1) Girl Scout group had a lower basal metabolic rate than the subjects of square meter per hour to be 34.87. Richardson (25) reported the mean basal metabolic rate of 25 Kansas women between 25 and 30 years of age as 32.21 Calories per square meter per hour. These three investigations indicated a general tendency of basal metabolism to decrease with age, which is consistent with the conclusion of McKay and Patton (19) who stated that "basal metabolism decreases as age increases with perhaps a slight rise during the pre-puberty period until adulthood is reached."

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Table 2

Mean basal metabolism of Kansas women 16 to 30 years of age

Age yr.	No.	Mean Cal./sq.m./hr. all[1]	Mean Cal./sq.m./hr. check[2]
16	13	35.0	32.6
17	17	35.3	35.3
18	33	34.2	34.2
19	39	33.1	32.9
20	18	34.7	34.5
21	9	34.7	34.8
22	6	33.7	33.7
23	1	32.9	31.9
24	2	31.9	32.3
25	6	32.7	30.3
26	7	32.8	32.4
27	8	34.1	33.6
28	3	32.8	32.6
29	2	32.0	32.6
30	2	31.0	31.1

Mean Cal. / sq. m. / hr. calculated from the results of

(1) Richardson (25)
(2) Kansas State Cooperative Regional Study--Unpublished material
(3) Present Study

1. Includes all of the four tests given to each subject
2. Includes only those tests which check within 5 per cent of each other

Table 3

Comparison of basal metabolism of girls from five states in mean calories per square meter per hour

State	No.	16 years Calories		No.	17 years Calories	
		all[1]	check[2]		all[1]	check[2]
Minnesota				3	36.40	36.40
Iowa				17	35.88	35.78
Ohio				2	33.06	33.06
Oklahoma				3	35.40	35.50
Kansas	13	34.98	32.96	17	35.32	35.32
Mean	13	34.98	32.96	42	35.53	35.49

1. Includes all the four tests given to each subject.

2. Includes only those tests which check within 5 per cent of each other.

Table 4

Basal metabolism of 16-17 year age groups from various studies

Study	16 years				17 years			
	No.	Av. Cal. / 24 hr.	Av. Cal. / kg. / 24 hr.	Av. Cal. / sq. m. / hr.	No.	Av. Cal. / 24 hr.	Av. Cal. / kg. / 24 hr.	Av. Cal. / sq. m. / hr.
Benedict's Girl Scouts (1923)	11	1170	21.9	31.0	12	1258	21.8	32.3
Blunt et al. (1926)	2	1317	25.1	34.5	3	1543	25.7	34.8
Wang et al. (1936)	3	1272	26.4	36.1	2	1357	22.7	34.7
McKay (1930)	20	1326	25.2	36.0	32	1381	25.3	36.6
This Study	12	1304	23.8	34.2	13	1273	24.8	34.9
Mean of all	48	1281	24.2	34.3	62	1342	24.4	35.3

Blunt et al. (5), Wang et al. (32), McKay (17), and the present study. However, the range of variation was not great. In comparing the results of the 17-year age group in Tables 3 and 4, there is a notable agreement between the 35.49 mean Calories per square meter per hour calculated from 42 subjects (Table 3) and 35.3 mean Calories per square meter per hour calculated from 62 subjects (Table 4).

Disregarding age, the heat production per square meter per hour remains approximately the same with the increase of surface area (Table 5). There is a slight tendency toward an increase of the average calories per 24 hours with the increase of surface area.

There is a general trend of increased heat production per kilogram with decreased weight regardless of age (Table 6). McKay (17) found similar results in her study on children between 14 and 18 years of age. The data from McKay's study on the younger age group of 14 and 15 years showed a slightly higher heat production per kilogram per 24 hours than the 16-17 year age group in this study. McKay obtained 27.3 mean Calories per kilogram per 24 hours on the 14-year age group and 26.6 on the 15-year age group. The results obtained in this study were 23.8 mean Calories per kilogram per 24 hours on the 16-year age group and 24.8 on the 17-year age group.

Table 5

Basal metabolism of 25 Kansas girls, 16 and 17 years old, as referred to surface area

Surface area	No. cases	Av. Cal. / 24 hr.		Av. Cal. / sq.m. / hr.	
		all [1]	check [2]	all [1]	check [2]
1.37-1.41	1	1309.03	1265.60	39.80	38.49
1.41-1.45	3	1236.38	1215.40	35.78	35.34
1.45-1.49	3	1227.15	1190.17	34.58	33.68
1.49-1.53	3	1269.14	1237.99	35.25	34.24
1.53-1.57	5	1302.08	1282.09	35.18	34.45
1.57-1.61	4	1344.20	1346.60	36.03	35.08
1.61-1.65	2	1317.12	1317.12	33.66	33.66
1.65-1.69	2	1392.62	1375.47	34.70	34.26
1.69-1.73	1	1365.48	1365.48	33.57	33.57
1.73-1.77	1	1457.88	1457.88	34.52	34.52

1. Includes all of the tests given to each subject.
2. Includes all of those tests which check within 5 per cent of each other.

Table 6

Basal metabolism of 25 Kansas girls, 16 and 17 years old, as referred to weight

Weight in kg.	No. cases	Av. Cal. / kg. / 24 hr.
65.0 - 67.5	1	21.57
62.5 - 65.0	1	21.95
60.0 - 62.5	2	23.09
57.5 - 60.0	2	24.57
54.0 - 57.5	4	23.09
51.5 - 54.0	5	23.52
48.0 - 51.5	5	25.32
45.5 - 48.0	2	25.49
43.0 - 45.5	3	27.38

CONCLUSIONS

1. In a study of the basal metabolism of 25 Kansas girls between 16 and 18 years of age, the mean basal metabolic rate in Calories per square meter per hour, was 34.21 for the 16-year old girls, 34.94 for the 17-year old girls, and 34.59 for the entire group.
2. The observed results showed an average deviation, from the Aub-DuBois standards as modivied by Boothby and Sandiford, of -11.15 per cent for the 16-year age group, -6.64 per cent for the 17-year age group, and -8.80 per cent for the entire group.
3. The basal metabolic rate of the 16- and 17-year age group was approximately the same as that of older subjects until the age of 25 or thereabouts, when there was a slight tendency toward a decrease with an increase of age.
4. The mean Calories per square meter per hour were closely proportional to the surface area of the body.
5. Disregarding age, the heat production per kilogram increased with decreased weight.

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