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THE ENERGY METABOLISM OF TEN HOSPITAL CHILDREN

BETWEEN THE AGES OF TWO MONTHS AND ONE YEAR *

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INTRODUCTION

In a study of the energy requirement of the new-born child by Bailey and Murlin,¹ it has been shown that when exposed to a temperature between 26 and 29 C. the sleeping infant falls far short of producing as much heat per unit of body surface as does the adult. It was seen also that a thin baby produced more heat per unit of surface and much more per unit of weight than a fat baby of the same age placed under exactly the same circumstances. These differences were so striking as to suggest a further study of the metabolism of children of different weights and of different ages, with special reference to the influence of body fat on the heat production. Aside from hereditary influences on the body size, the chief cause of difference in weight of normal infants at birth, or, for that matter, at any other given age, is the proportion of fat, which in turn is determined by the nutritive condition. Does this fat, deposited for the most part beneath the skin, reduce the metabolism per unit of weight because it protects against heat loss by radiation and conduction, or because it serves as so much ballast, so to speak, thereby cutting down the proportion of active tissue where heat is produced?

This question of the proportion between the active and the inactive tissue, and its influence on heat production has been raised wherever marked discrepancies have been found in the application of Rubner's law of surface area. Rubner,² himself, when he first observed such discrepancies in the application of this law (at that time but recently demonstrated for animals) to human subjects of different ages, hinted at a difference of functional capacity, but dismissed the idea as one of

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1. Bailey and Murlin: *Proc. Soc. Exper. Biol. and Med.*, 1914, xi, p. 109; also *Am. Jour. Obst.*, February, 1915.

2. Rubner: *Ztschr. f. Biol.*, 1885, xxi, 397.

minor importance. Magnus-Levy and Falk,³ however, in their study of the influence of age on the respiratory metabolism very clearly expressed the possible significance of differences in this proportion.⁴ Again, in his work on myxedema, Magnus-Levy⁵ raises the question whether the lower metabolism of patients suffering with this disease may not be due to the fact that they have actually a smaller functioning mass of protoplasm.

In his work with Heubner on infants, Rubner⁶ explains every difference in the metabolism per unit of surface as due to differences in the dynamic action of the food or to differences in muscular activity, and does not consider the difference in the amount of body fat possessed by their well-nourished infants as compared with their atrophic one. Schlossmann,⁷ however, although a firm believer in the application of Rubner's law even to atrophics, in answering the criticisms of Kassowitz is obliged to admit that the law presupposes a normal amount of subcutaneous fat.⁸

Placing the emphasis on the heat production rather than on the heat loss, Howland⁹ also limits the law of surface area to the "well and moderately nourished" children, holding that "it does not seem to apply for the greatly emaciated child with almost complete absence of muscular tissue."

The subject has received extended consideration for the first time at the hands of Benedict and Talbot¹⁰ in their monograph on the "Gaseous Metabolism of Infants." Comparing the sleeping metabolism of sixty-one different infants¹¹ varying in nutritive condition from

3. Magnus-Levy and Falk: *Arch. f. Anat. u. Physiol.*, 1899; *Phys. Abth. Suppl. Band*, p. 314.

4. Thus: "Wir gehen wohl nicht fehl, wenn wir dem als Todtes Reserve und Heizmaterial im Bindegewebe und Nervensysteme eingelagerten Fette (wie auch dem Glykogen) jeden eigenen Umsatz ganz absprechen, wenn wir den Knochen und dem Bindegewebesgerüste nur einen geringen zuerkennen, und den grössten Betrag des Kraftumsatzes und des Gaswechsels den protoplasmareichsten Geweben, den Muskeln, Drüsen u. s. w. zutheilen. Dass die Gewichtseinheit des Protoplasmas des Trägers thierischer Functionen im kindlichen Alter einen erheblich höhern Umsatz zeigt als in der Zeit vollen Reife geht ja aus den absolut hohen Zahlen der Kinder klar hervor."

5. Magnus-Levy: *Ztschr. f. klin. Med.*, 1904, lii, 201.

6. Rubner: *Ztschr. f. Biol.*, 1899, xxxviii, 375 et seq.; also *Ztschr. f. exper. Path. u. Ther.*, 1905, i, 18 et seq.

7. Schlossmann: *Ztschr. f. Kinderh.*, 1912-'13, v, 227.

8. "Die Voraussetzung dabei ist natürlich einmal eine relative Norm der Umgebung, zum andern aber eine relative normale Oberfläche des Kindes. d. h. eine funktionierende und gut passende Haut mit dem normale Fettgehalt der Unterhaut" (p. 231).

9. Howland: *Tr. XV Internat. Cong. Hyg. and Demog.*, Washington, 1912, ii, 448.

10. Benedict and Talbot: *Carnegie Institute of Washington, Publ.* 201.

11. Benedict and Talbot: *Studies in the Respiratory Exchange of Infants*, *AM. JOUR. DIS. CHILD.*, July 1914, p. 1.

extreme atrophy to "very much overweight" and in age from a few hours to 17 months, they find no parallelism between the heat production and body surface, as given by any of the known formulas, and none between the heat production and body weight. They conclude that it is the "active mass of protoplasmic tissue which determines the fundamental metabolism." The only measure of this which they propose, however, is one of proportion between age on the one hand, and weight and height on the other. Thus by comparing children having the same weight and height, but of different ages, their results show that the older child invariably has the higher metabolism, the reason given being that in order to have the same weight as a younger child, the older must have relatively less body fat and therefore relatively more active tissue.

Before it was known to us that Benedict and Talbot were engaged on this problem plans had been made by us to carry through a comparison of the heat production amongst a similar assortment of infants, using as an expression of the proportion of fat to active tissue the specific gravity of the child's body, as nearly as this could be determined.¹²

12. The method developed in Pfaundler's laboratory by Kastner (*Ztschr. f. Kinderh.*, 1912, iii, 391) for obtaining the volume of the child's body was adopted as the most practicable method available, but it yields only approximate results. In fact, no method of obtaining the volume of the living body exclusive of the air of the lungs and air passages is at this time possible for children who are too young to control the respiration at the will of the observer. Nevertheless, it was possible to get on successive days good duplicate readings for the volume of the body up to the chin by displacement of water, if patience enough were exercised to secure absolute quiescence on the part of the child; and measurement of the head by Kastner's method was found by controls made on eight cadavers of infants in this hospital to be fairly accurate. The "approximate specific gravity" as determined in this way did tend to equalize the metabolism per unit of weight. (Cf. *Proc. Soc. Exper. Biol. and Med.*, 1914, xi, 115). This seems, however, to have been mere coincidence, or else there is some relation between chest capacity and size of head (the two factors most difficult to estimate accurately) on the one hand and the amount of fat on the other. Two other methods of determining the volume of the child's body have been attempted. Both were suggested by Pfaundler's discussion (*ibid.*, iii, 413) of a somewhat similar method. One of these consisted in running a known amount of water into a flask set inside the closed inner chamber of the incubator and noting the rise in pressure on a manometer communicating with the inner space, (a) with the child inside and (b) with the child not inside. A direct proportion then would subsist between the inner volumes with and without the child and the changes in pressure. The original volume of the empty box being known the volume of the child would be obtained by difference. The second method consisted in raising the pressure by admitting oxygen from the oxygen cylinder; but instead of attempting to admit the same amount of oxygen with the child in the box and with the box empty, the attempt was made to produce the same rise in pressure both times and then to calculate the volumes from the amount of oxygen lost from the cylinder, as determined by weighing, in the two measurements. The chief difficulty in both cases lay in the lag of the thermometers indicating the air temperature. Either method can be employed while the child sleeps without disturbing him in any way.

The discovery of comparatively recent analyses on the actual composition of the bodies of normal, atrophic and fat infants by Sommerfeld, Steinitz¹³ and Steinitz and Weigert¹⁴ have made it clear to us, however, that the *actual specific gravity cannot vary sufficiently to account for differences in metabolism*. Moreover, the constancy of the percentage of nitrogen in children of different weight was a distinctly surprising discovery, the significance of which will be commented on in the final discussion of results. Table 1, compiled from various sources, exhibits the variation in actual composition of the child's body in widely different states of nutrition.

TABLE 1.—COMPOSITION OF INFANT'S BODY COMPILED FROM VARIOUS AUTHORS

Author	Condition	Age	Weight	In 100 Parts				
				Water	Dry Sub.	Ether Extr.	Ash	N.
Camerer and Soldner*....	Normal new-born	Av. or six infant at term	2,820	71.8	28.2	12.3	2.7	1.8
Sommerfeld†	Normal infant	3 months	4,340	70.15	29.85	13.4	2.73	2.27
Steinitz No. III.....	Atrophic infant	3 months	2,625	79.9	20.1	1.45	2.73	2.3
Steinitz No. IV.....	Atrophic infant	2½ mos.	1,960	82.3	17.7	1.8	3.2	2.13
Steinitz No. V.....	Atrophic infant	3¾ mos.	3,220	79.8	20.1	1.98	3.34	2.51
Steinitz and Weigert.....	Fat infant†	4 months	3,711	58.94	41.06	24.17	2.98	2.25

* Camerer and Soldner: Ztschr. f. Biol., 1902, xliii, 1.

† Sommerfeld: Arch. f. Kinderh., 1900, xxx, 253.

‡ This child had been fed by its mother on gruels containing a large preponderance of carbohydrates.

It is obvious from these figures that fluctuations in the amount of fat are offset by fluctuations in the content of water; in other words, that fat instead of replacing protein or being added to the other constituents of the body, actually replaces water, leaving the percentage of protein the same. Calculated to a fat-free basis, these infants had very nearly the same content of water.

From these analyses may be calculated the actual specific gravity of a normal, an atrophic and a very fat infant (Table 2).

Later it will be seen that differences in the heat production between children of different nutritive condition are much greater than those represented by these specific gravities. It remains important, however, to obtain as much accurate information as possible on the heat produc-

13. Steinitz: Jahrb. f. Kinderh., 1904, lix, p. 447.

14. Steinitz and Weigert: Beitr. z. chem. Physiol. u. Path. (Hofmeister's), 1905, vi, 205.

tion of different types and to consider the value of the unit of weight as contrasted with the unit of surface. Comparisons will be made with the results found by all authors who have used methods at all comparable with ours.

The methods employed in this series of observations will be considered briefly, after which the results and their significance will be taken up.

TABLE 2.—METHOD OF CALCULATING SPECIFIC GRAVITY FROM DATA IN TABLE 1

	Per Cent.		Specific Gravity		
Atrophic child—					
Water	80	×	1.00	=	80
Fat	1.73	×	0.9 *	=	1.557
Ash	3.00	×	2.25†	=	6.75
Protein and extractives.....	14.6	×	1.5 ‡	=	21.90
					1.1020 Sp. Gr.
Normal child—					
Water	70.15	×	1.00	=	70.15
Fat	13.11	×	0.9	=	11.799
Ash	2.73	×	2.25	=	6.143
Protein and extractives.....	14.01	×	1.5	=	21.015
					1.0910 Sp. Gr.
Fat child—					
Water	58.94	×	1.00	=	58.94
Fat	24.17	×	0.9	=	21.753
Ash	2.98	×	2.25	=	6.705
Protein and extractives.....	13.91	×	1.5	=	20.865
					1.0826 Sp. Gr.

* Biochem. Handlexicon, 1911, iii, 175.

† Pfaunder: Ztschr. f. Kinderh., 1912, iii, 413.

‡ Estimated.

AUTHORS' EXPERIMENTS

The apparatus described by Murlin¹⁵ was used in this series of observations. Through the courtesy of Dr. L. E. La Fetra, chief visiting physician to the children's service, and of the hospital authorities, it was set up in the laboratory off the children's ward, and special connections to the water and electric supplies of the building were provided. We wish to express at this point our very great obligation to Dr. La Fetra for his unfailing helpfulness and encouragement. While the work is such as properly to require the attention of a special nurse and the subjects to be used should ideally be cared for in a special room or ward, through the hearty cooperation of the house physician, Dr. L. C. Schroeder and the head nurse, Miss Hein, very little inconvenience was experienced in obtaining subjects wanted at the proper time or in the proper condition as to food, sleep, etc. Our hearty thanks to these persons, as also to Dr. B. Kramer, who assisted in the last few weeks of the work, are due, and are here gratefully recorded.

15. Murlin: AM. JOUR. DIS. CHILD., January, 1915, p. 43.

The daily routine, while varied to suit the convenience of the observers, who were ourselves, was usually as follows: The water and power were turned on the incubator at about 9:30 a. m. By 10:30, as a rule, temperature conditions inside the incubator, even in the coldest weather, were perfectly stable and constant. The child selected, having been kept awake since the early morning feeding at 5 or 6 a. m., was brought to the laboratory at about this time. He was there first weighed stripped, immediately after this was immersed for the volume determination,¹² and as soon as clothed again was given food just before entering the incubator. The first period could as a rule be started within from fifteen minutes to half an hour after sealing up the inner chamber. On this schedule the respiratory observations were completed by about 1 p. m. Rarely an experiment was conducted in the afternoon also.

METHODS

1. *Heat Production.*—It was determined at the outset to make the measurement of the respiratory exchange as accurate as possible and to take into account the nitrogen of the urine, so that no factor should be lacking in the exact estimation of the heat production, which was calculated by the method of Zuntz and Schumburg.¹⁶ The exact determination of the oxygen absorption even from a chamber of small dimensions such as the one here employed, can be made only by analyzing the air at the beginning and end of each respiratory period. For example, if the child should void urine during the course of the period, the water vapor in the air immediately would rise very considerably, and if he should cry actively for as much as ten minutes, both the water vapor and the carbon dioxid would rise very perceptibly, thereby excluding some oxygen, which is fed in according to the air tension, and diminishing the apparent absorption. Many instances of this sort could be given from this series of experiments in which the respiratory quotient would have been many points below or above the actual value if this correction for the composition of the air had not been made. The conditions obtaining in an alcohol check experiment even where the same amount of oxygen is used up as in the experiment with the child, are not at all controlling; for in this case the amount of carbon dioxid and water vapor is very constant, and residual analyses are not so important, although they have in these experiments always been made. In view of the fact that Benedict and Talbot have

16. Zuntz and Schumburg: Studien zu einer Physiologie des Menschen, Berlin, 1901. See also Williams, Riche and Lusk: Jour. Biol. Chem., 1912, xii, 349.

made all of their heat calculations on the basis of the carbon dioxide instead of the oxygen, it should be noted that a much greater error¹⁷ is involved in this method when the respiratory quotient is not known exactly for the period under consideration than when the oxygen is used as the basis. Corrections were made also for temperature and barometric changes for each and every period of the experiments.

2. *Collection of Urine.*—The collection of urine in twenty-four-hour periods was accomplished successfully, though not without some difficulty, even with the female child. With Children 4 and 6 (Table 4), it may be seen how the total nitrogen in the urine varies but little from day to day so long as the food is constant, as to both quantity and quality, while with Child 3 may be seen the effect of varying the quality of the food. Since in all of these cases the food was purposely kept as nearly constant as possible, having regard for the welfare of the child, the urine was not collected for every experimental day, and in several instances was preserved for analysis on one day only.

The bed or frame used in the collection of the urine was one similar to that described by Hoobler,¹⁸ but small enough to be admitted to the inner chamber (Fig. 1). When urine was being collected for the twenty-four hours of which the experimental period was a part, the urine bottle was placed in the chamber with the child. When urine was not wanted for the period the child was provided with a double diaper to prevent vaporization as much as possible.

3. *Uniform Conditions.*—For the purpose of this investigation it was essential that the factors of food, muscular work and environing temperature should be as nearly constant for each individual as possible and should be comparable for different individuals. In some respects the conditions of inanition adopted by Schlossmann and Murschauser and Howland for the determination of the basal metabolism would have been more nearly ideal for the purpose. Judging by the difficulties experienced by Schlossmann and Murschauser in getting complete muscular rest, however, and with the feeling that the matter of muscular rest was much more important than the dynamic action of food, it was deemed best to feed the child as much as necessary to obtain, if possible, two continuous hours of sleep. It may be seen from Table 5 that in many instances there were two successive hours of sleep. More often the sleep terminated some time during the second

17. See e. g. A. Loewy: Oppenheimer's Handbuch der Biochemie, iv, p. 278, for the differences in heat value of a liter of oxygen and carbon dioxide. For a detailed discussion of this matter Cf. DuBois and Gephart, Arch. Int. Med., to appear soon.

18. Hoobler: AM. JOUR. DIS. CHILD., 1912, iii, 253.

period, or, if it did continue throughout the second, was less quiet than the first.

4. *Records of Movements.*—In order to secure the advantage of darkness in keeping the children asleep, a blanket was suspended across the glass front of the incubator as soon as the respiration chamber was closed. This made it impossible to see the motions of the subject. Furthermore, it was desired to make observations as to the relation between the pulse and respiration rates and the heat production, and to rule out the personal equation in making the enumeration of these movements. A means was devised, therefore, for recording both the pulse and the respiratory movements on a smoked paper.

A. Pulse: A small cuff such as is used in making blood-pressure determinations in the infant¹⁹ was placed about the left thigh. From this a rigid-walled tube was led to a glass connection passing through the wall of the incubator, thence to a T-tube on top of the incubator, one limb of which passed to a small air-pump and the other to a second T-tube. To the second T a mercury manometer was connected by one limb and a pressure-reducing bottle by the other (Fig. 1). From the pressure-reducing bottle, finally, a transmission tube led to a recording tambour covered with a piece of very thin rubber membrane. A pressure of from 30 to 40 mm. of mercury was found to be sufficient to give a legible motion to the lever, and it was found that this pressure did not interfere either with the circulation or with the repose of the child. After several trials it was found that two very thin finger-cots placed one inside the other sufficed to reduce the pressure in the pressure bottle and at the same time to transmit a sufficient wave to the tambour for a legible record on smoked paper.

Two kymographs of the Sherrington type were arranged as a long paper kymograph on top of the incubator. One complete revolution of this paper could be made to coincide with an hour's observations. The pulse naturally was not recorded legibly when the leg was being moved, although, as may be seen in Figures 5 and 6, it was often possible to count the pulsations even while the child was crying. Before the graphic method had been satisfactorily worked out the pulse with Child 1 was for a few days (Table 5) counted by means of the stethoscope. The only objection to this graphic method of counting the pulse which was encountered was the labor of enumerating the pulse waves of the record. Because of this, with the last three children the stethoscope was again used.

19. Hoobler: Med. Rec., New York, December, 1911.

Fig. 1.—Showing arrangement of small cuff on the leg of infant for recording pulse, and small pneumograph around chest for recording respirations. The rubber tubing connecting with the tambours on top of the incubator are seen penetrating the outside wall. *P*, tubing for pulse; *R*, tubing for respiration.

Fig. 2.—Showing arrangement of recording devices on top of the incubator. The tube *P* connects a T tube (1) with the hand pump and (2) with another T, which in turn connects with the mercury manometer *M*, and the pressure reducing bottle *PB*. From the pressure-reducing bottle a final tube leads to the recording tambour.

B. Respiration: For recording the respiratory movements and, incidentally, movements of the body and arms, a very short pneumograph of the type made by the Harvard Apparatus Company was used. The rubber tubing ordinarily used on these pneumographs not being sufficiently distensible for the baby's chest, it was replaced by a tube made from the finger of a surgeon's rubber glove. The one tube served throughout the entire series of observations.

C. Time: A record of the time in seconds was obtained simultaneously with the pulse and respiration by means of a Jacquet time recorder.

Fig. 3.—Sample from record for C. P., March 7. In this and the following figures upper tracing of each group *R* represents the respirations; the middle one, *P*, the pulse, and the lower one, *T*, the time in seconds. The record shows several readjustment movements, and the method of counting the pulse and respirations by drawing parallel lines twenty seconds apart perpendicular to the time record as base line.

Samples of the tracings secured by these methods are shown in Figures 3, 4, 5 and 6. With every child but one (C. M.) at least one complete hourly period as quiet as those shown in Figures 3 and 4 was obtained. Experience soon taught that when a child did not sleep soon after feeding it was time wasted to prolong the observation. In only the one case above mentioned, therefore, was the child permitted to indulge in prolonged crying. Naturally it was not difficult to tell at once when a child fell asleep. The perfectly regular respiration for two minutes or more could mean nothing else and even when the respirations were not perfectly regular the absence of larger spikes denoting continuous or frequent grosser movements always made this point perfectly certain. From these tracings, except in the instances

Fig. 4.—Sample from record for W. L., March 25, sleeping throughout. Three turns about the kymograph are intercepted. The respiration record shows type of irregular respirations (Cheyne-Stokes) referred to in Table 5.

Fig. 5.—Sample from record for E. N., March 28, showing the character of the tracings obtained with a moderate degree of restlessness.

noted in the footnotes, were obtained the data given in Table 5 regarding muscular activity, pulse and respiration.

The Cheyne-Stokes type of respiration is common in these children. Sometimes a perfectly regular respiration wave would prevail through one period of the experiment and in the next the predominate form would be the Cheyne-Stokes. It was impossible to correlate its occurrence in any definite way with events in the alimentary system.

It is a perfectly familiar fact that a child even when perfectly healthy will not lie absolutely still for long at a time even in the most profound sleep. Now and then a sensory irritation from some part of the body will cause a series of movements which for convenience have been designated "readjustment movements." Figure 3 shows what is meant by this term. They occur in almost every record of the sleeping child, but recurred most frequently in the case of Child 4 on the third day of the protein milk formula.

Fig. 6.—Sample from record for J. S., March 23, showing the character of tracings obtained with continuous restlessness and crying. At C and C the child was heard to cry out. The record shows that it is often possible to count the pulse even while the child is crying.

When the child waked after a sleeping period of an hour or two it did not lie still long. Rarely it would fall asleep again. Most commonly fretting or crying soon began and continued to the end of the period. The motions produced were unmistakable. Crying could also be heard even when the stethoscope was not used, by listening near the rubber bag used as a tension equalizer (Fig. 2). Table 5 exhibits in a number of instances the influence of crying a definite number of minutes in contrast with a perfect sleeping period.

5. *Temperature of the Incubator.*—The temperature shown in Table 4 represents the average temperature at the beginning and end of each period, respectively, as shown by two thermometers, one in

the inner chamber and one in the outer.²⁰ The temperature of the copper wall of the box, and hence of the air exposed to it inside, obviously was determined quite as much by the outside temperature as by the temperature of the air inside just above the child. From many experiments with alcohol checks it was learned that the average of the two thermometers gave a more accurate index than the average of all four thermometers. As may be seen from Table 4 this average temperature never fell below 27 and rarely rose above 29 C. The child on the bed was clothed with only a single garment, a knit or flannel shirt, or wrapper, and it was found that this temperature was most conducive to quiet sleep. Only when the child cried actively for several minutes did it perspire. Except in very few periods the temperature did not vary more than a half degree throughout the hour.

SUBJECTS OF EXPERIMENTS

CHILD 1.—W. So., admitted to Bellevue Hospital, pediatric division, Jan. 23, 1914, aged 1 year. The child was a perfectly well boy; he had never been ill and was brought to the hospital because his mother was about to be confined in the School for Midwifery and there was no one at home to take care of him. Physical examination was negative throughout. He weighed 21 pounds and 8 ounces on admittance. March 9 he was discharged from the hospital in care of his mother. While in the hospital the child took his feedings well, did not vomit, and the stools were normal.

CHILD 2.—A. Sa., admitted to Bellevue Hospital Feb. 9, 1914, aged 7 weeks. The child was a perfectly normal, healthy boy and was brought into the hospital because the mother was to undergo operation. The physical examination was negative throughout. While in hospital the child was fed partly on breast-milk and partly on diluted cow's milk. The child did not vomit; took feedings well; stools normal.

CHILD 3.—C. P., admitted to Bellevue Hospital Dec. 21, 1913, aged 1 month. Chief complaint was that of diarrhea and vomiting. Two weeks previous to admission the child was taken from the breast. Shortly thereafter he began to have loose, green stools, at first five to six daily; on admission two to three a day. During the three days before admission child had been vomiting four to six times daily after the cow's milk feeding. He cried almost constantly. Weight on admission 4 pounds and 3 ounces. Physical examination showed emaciated infant; eyes, cheeks and anterior fontanelle sunken. Child was put in premature room and fed on breast-milk and gradually increased in weight to 5 pounds and 9 ounces; stools became normal; vomiting ceased. Metabolism studied at this period. Died one week later.

CHILD 4.—E. N., aged 3 months, brought into Bellevue Hospital, pediatric division, because mother was undergoing an operation in Ward 16. Father had tried to care for child at home but when he cried a great deal (because of over feeding) and began to vomit, father brought him to hospital. Physical examination showed child to be a perfectly normal male, fairly well nourished, without the appearance of being sick. When placed on proper cow's milk dilutions vomiting ceased, stools were normal and child was in good condition at time metabolism studies were undertaken.

CHILD 5.—J. Sm., admitted to Bellevue Hospital, pediatric division, Feb. 22, 1914, 11 months of age, weight 11 pounds and 10 ounces. Child was brought

20. AM. JOUR. DIS. CHILD., January, 1915, p. 43.

into the hospital as a well baby, the mother being in the gynecological ward for an operation. Was only moderately nourished child, but physical examination showed no pathologic conditions except a discharging ear. At the time the metabolism studies were made child was taking feedings well; stools were normal; no vomiting.

CHILD 6.—W. L., aged 2 months; was deserted by mother after having been left in hospital. Child was perfectly normal, taking its feedings well; stools normal and no vomiting.

CHILD 7.—C. Ma., a breast-fed girl baby, 10 months old on March 10, 1914, was brought into pediatric division, Bellevue Hospital, while mother was undergoing an operation in gynecologic ward of same hospital. The child was a fat, healthy baby at the time metabolism studies were undertaken.

CHILD 8.—C. D., an undernourished white boy, admitted May 13, 1914, aged 3 months, was brought to hospital for regulation of its diet; had been fed on breast until two weeks before admission. Since then he has been fed on diluted cow's milk; vomited and had green stools. On proper diet vomiting ceased. Stools became normal and child was discharged to its mother June 23 in excellent condition.

TABLE 3.—SUMMARY OF DATA DESCRIBING SUBJECTS

Name	Age, mos.	Weight, gm.	Sex*	Characterization of Condition
E. H.	2½	4,690	♂	Normal baby, average weight.
A. Sa.	2	5,810	♂	Perfectly healthy baby, considerably overweight.
W. L.	2	4,364	♂	Normal baby, near average weight.
E. N.	3	4,115	♂	A healthy child. His underweight only temporary, due to wrong diet shortly before entering hosp.
C. P.	3	2,462	♂	A markedly atrophic child in last stage of marasmus.
C. D.	4	3,375	♂	Considerably undernourished, and underweight. Disturbance of nutrition only.
M. Me.	5¾	6,470	♂	A child whose nutrition appeared entirely normal, but who no doubt had an incipient tuberculous infection. Normal weight.
C. Ma.	10½	9,465	♀	A healthy child considerably above the average weight due to excess of fatty tissue.
W. So.	11-12	9,373	♂	Healthy child, normal weight.
J. Sm.	12	5,802	♂	Much underweight. No proof of a diseased condition though suspected of hyperthyroidism after observations on metabolism.

* In this column ♂ stands for male and ♀ for female.

CHILD 9.—E. H. (foundling), brought in by messenger June 16, 1914, was a healthy boy about 8 weeks of age with no physical abnormalities. While in hospital child gained in weight; stools were normal. On July 2 he was transferred to Foundling Hospital as a normal healthy baby.

CHILD 10.—M. Me., admitted to hospital on June 7, 1914, aged 5 months. Mother in hospital very ill with tuberculosis; subsequently died. Child showed positive von Pirquet; Roentgen-ray revealed no enlargement of bronchial lymph-nodes. Temperature 99.4 F. *after* experiment on June 30. July 1 temperature rose to 101.4 F. gradually subsiding, reaching normal July 4, otherwise temperature was within normal limits. The child was a well-developed boy with no evident signs of illness and when discharged appeared to be in good condition.

GROSS RESULTS

In presenting the results just as they came from the laboratory in chronologic order (Table 4), it may be stated at the start that in only five cases (one-half the total number reported) were the conditions of food, muscular repose, etc., what we would call *entirely* satisfactory. These can be readily picked out of the table by the fact of close agreement between the results *on successive days*. The ideal which was sought embraced the following experimental conditions: (1) the same food as regards quantity and quality on successive days for the same child; (2) approximately the same proportionate amount for different children; (3) the respiration experiment starting at nearly the same time after feeding on successive days, e. g., Child 4; (4) the child sleeping at least one full hour of the respiration period; (5) a uniform temperature. In the present state of our knowledge, conditions less rigid than these cannot meet the requirement of satisfactory proof or disproof of such a law as Rubner's law of surface area (see "Discussion" toward end of article).

The first and last of these conditions were the ones most easily fulfilled in our experiments and for evident reasons. The routine feedings of a given amount of food to well babies is readily accomplished with the help of well-trained nurses. The last feeding just before the respiration period was given by one of us and the amount taken (ounces on the nursing bottle) was noted. The calculation of the calories distribution in the food and the total amount in the last feedings is based on the average composition of the milk (and dextrin-maltose) regularly used in the hospital.

As for giving the same proportionate amount of food to different babies, one is met at the outset with the dilemma of choosing a unit. Shall children be fed according to weight, surface area or age? In practice any of these standards must be constantly checked by observations as to the growth, digestion, etc., so that if a certain standard is selected (say 80 calories per kilogram per day or 10 calories per kilogram per feeding) conditions may arise necessitating a change, and this is very disconcerting to well-laid laboratory plans. Such difficulty at the very outset was met with in the case of Child 1 who developed a diarrhea on February 12 and the diet had, accordingly, to be changed. The same was true of Child 7.

The necessity for beginning the respiration experiment as nearly as possible the same length of time after the last feeding appeared early in the series. For example, with Child 1 (W. S.), February 10 and 11, when the experiments began twenty-three and twenty minutes, respectively, after feeding, the metabolism of the first hour (sleeping) was very nearly the same for the two days; while the next day when

TABLE 4.—GROSS RESULTS OF METABOLISM FINDINGS OF TEN CHILDREN ARRANGED CHRONOLOGICALLY

Date	Name and Age	Condition	Weight	Food Distribution of Calories in Per Cent. of Total	Last Feedings		Respiration Period	CO ₂ Elim. L.	O ₂ Abs. L.	R. Q.	N in 24-Hour Urine	Calories Per Hour	Temp. of Resp. Incubator	
					Ant. oz.	Time							B.	E.
1914 2/ 4	Child 1, W. So., 11-12 mos.	Normal boy	9,290	P21.9; F49.8; OH28.3	8	A. M. 9:00	11-01-12:05	5,724	7,130	0.80	.....	31.14	29.5	29.6
2/ 6			9,479	" "	8	P. M. 2:15	2:35- 3:35	4,540	5,573	0.81	4,130	26.50	27.6	27.7
2/10			9,373	" "	8	A. M. 10:30	10:43-11:43	4,122	5,012	0.82	4,298	23.88	27.6	28.0
2/11			9,440	" "	8	.....	11:43-12:44	4,803	5,611	0.85	.....	26.45	28.0	28.1
2/12			9,215	" "	8	11:00	11:20-12:20	4,345	4,929	0.88	.....	23.51	28.0	28.5
2/12			9,215	Formula	10	11:00	12:20- 1:21	4,534	5,415	0.83	.....	25.43	28.5	28.8
2/26			9,555	P45; P23.6; OH31.4	10	11:00	12:15- 1:15	4,411	5,506	0.79	3,948	26.23	28.8	29.4
2/26			9,555	Formula	10*	9:00	11:15- 2:15	5,021	5,872	0.85	.....	28.25	28.3	28.8
2/26			9,555	P22; F50; OH28	8	10:45	11:16-12:16	4,970	5,489	0.90	.....	26.72	28.8	28.7
2/13	Child 2, A. Sa., 2 months	Normal boy overweight	5,890	At breast	?	10:30	12:52- 1:32	1,545	1,811	0.85	.....	13.92	29.7	30.3
2/14			5,810	Form.P10; P22.5; OH67.5	3	9:00	12:22- 1:13	1,871	2,070	0.90	0.658	12.00	30.3	30.2
2/16			5,682	Mother's Milk	3	11:00	1:13- 2:04	2,406	2,700	0.89	.....	15.42	30.2	30.4
2/17			5,690	Mother's milk	3	9:00	10:29-11:31	2,164	2,509	0.86	0.812	11.78	28.4	28.6
2/27	Child 3, C. P., 3 months	Atrophic	2,462	Formula	3	10:30	11:21-12:23	4,050	3,859	1.04	.....	17.45	28.6	28.5
3/ 3			2,515	" "	3	10:30	11:27-12:27	2,301	3,051	0.75	.....	14.50	27.4	27.5
3/ 7			2,444	Formula	3	10:45	12:27- 1:27	2,581	2,914	0.88	.....	14.20	27.5	28.3
3/ 7			2,444	P12; F20; OH67	3	.....	.....	.....	.....	.....	.....	.....	.....	.....
3/10			2,434	Formula	3	9:00	11:48-12:48	1,570	1,448	1.08	.....	7.35	28.1	28.4
3/10			2,434	P11; F25; OH64	3	10:45	12:48- 1:48	1,430	1,429	1.00	.....	7.15	28.4	28.7
3/10			2,434	" "	3	9:00	10:40-11:40	1,569	1,448	1.08	0.602	7.35	27.7	27.8
3/10			2,434	Formula	3	10:30	11:40-12:40	1,369	1,499	0.91	.....	7.43	27.8	28.2
3/10			2,434	P11; F75; OH14	3	P. M. 1:00	3:08- 4:08	1,114	1,150	0.97	1.086	5.65	28.3	28.6
3/10			2,434	Formula	3	2:30	4:08- 5:05	1,140	1,324	0.86	.....	6.37	28.6	28.9
3/10			2,434	P29.6; F55.7; CH14.7	3	A. M. 9:30	10:32-11:32	1,364	1,675	0.81	1.330	7.97	29.1	29.2
3/10			2,434	Formula	3	.....	11:32-12:32	1,292	1,778	0.72	.....	8.27	29.2	29.9
3/17	Child 4, E. N., 3 months	Underweight	4,115	Formula	3	9:00	11:10-12:10	2,154	2,188	0.98	1.120	10.87	28.6	29.0
3/18			4,134	P10; F24; OH66	3	10:30	12:10- 1:10	1,968	2,208	0.89	.....	10.75	29.0	29.9
3/19			4,147	Formula	3	9:00	11:10-12:10	2,295	2,072	1.11	1.092	10.53	28.5	29.1
3/19			4,147	P10; F24; OH66	3	10:30	12:10- 1:11	2,503	2,432	1.08	1.064	12.04	29.1	29.7
3/19			4,147	" "	3	9:00	11:10-12:10	2,069	2,096	1.00	.....	10.47	28.8	28.9

3/21	Child 5, J. Sm., 12 months	Underweight	5,802	Formula P22;F50;OH28	7	9:00 10:45 9:00 10:45	92	11:23-12:23 12:23-1:23 11:00-12:00 12:00-1:00	4,081 3,450 3,557 4,104	4,202 4,366 4,096 4,477	0.97 0.79 0.87 0.92	3,780	20.74 20.50 19.78 21.88	23.8 23.1 29.0 29.2	29.1 28.8 29.2 29.2
3/23	.....	.....	5,713	"	7	.....	92	.....	.....	.....	.....	.....	.....	.....	.....
3/24	Child 6, W. L., 2 months	Normal	4,364	Formula P11;F25;OH64	3	9:00 10:10 9:00 10:15	39	10:45-11:45 11:45-12:45 10:35-11:35 11:35-12:35	1,905 2,416 2,015 2,036	2,152 2,673 2,193 2,986	0.92 0.90 0.92 0.87	0.924	10.56 13.00 10.74 11.69	29.1 29.2 28.3 29.1	29.2 28.8 29.1 29.1
3/25	.....	.....	4,371	"	3	.....	36	.....	.....	.....	.....	.....	.....	.....	.....
3/26	.....	.....	4,350	P12;F27;OH61	3	9:00 10:15 9:00 10:50	36	11:10-12:10 12:10-1:10	2,049 2,065	2,181 2,369	0.93 0.92	1,008	11.09 11.31	29.2 29.4	29.2 29.5
3/24	Child 7, C. Ma., 10½ mos.	Normal girl overweight	9,382	Whole milk P22;F50;OH28	8	P.M.	148	3:28-4:28	4,529	5,518	0.82	1.20	26.54	28.6	29.1
3/25	.....	.....	9,492	Form. (oil, whole milk) P22;F50;OH28	2	1:00 3:00 1:00 3:10	37	3:28-4:28	2,821	3,934	0.71	.....	24.50	28.7	29.1
3/26	.....	.....	9,465	Whole milk P22;F50;OH28	2	.....	53	4:13-4:58	3,013	3,819	0.78	.....	24.19	29.1	29.4
	.....	.....	.....	.....	8	.....	148	3:41-4:26	3,471	4,846	0.72	1,652	30.18	28.8	29.5
	.....	.....	.....	.....	2	.....	37	4:26-5:11 5:11-6:11	3,280 3,593	4,246 5,162	0.76 0.70	.....	27.54 24.09	29.5 29.8	29.8 29.3
6/10	Child 8, C. D., 4 months	Underweight boy	3,510	Formula P16;F25;OH69	4	M. P.M. 2:00	47	2:38-3:38	2,348	2,880	0.82	.....	13.16	28.1	27.1
6/11	.....	.....	3,375	"	4	M. P.M. 2:00	47	3:36-4:36	2,699	2,726	0.99	.....	13.61	27.1	28.0
6/18	.....	.....	3,440	"	4	M. P.M. 2:00	47	3:30-4:30	1,861	1,861	1.00	.....	9.26	28.3	27.9
	.....	.....	.....	"	3	M. P.M. 2:20	35	4:30-5:25	2,314	2,185	1.06	.....	11.89	27.9	28.4
	.....	.....	.....	.....	2	M. P.M. 2:20	35	2:39-3:39	1,786	2,267	0.79	0.896	10.79	27.1	27.8
6/24	Child 9, E. H., 2½ mos.	Normal boy	4,690	Formula P13;F28;OH69	4	M. P.M. 3:00	53	3:39-4:39	1,940	2,192	0.87	.....	10.67	27.8	27.9
6/26	.....	.....	4,657	"	4	M. P.M. 2:15	53	4:00-5:00	2,460	2,548	0.96	0.924	12.68	28.0	28.3
	.....	.....	.....	.....	4	M. P.M. 2:50	53	5:00-6:00	2,468	2,635	0.92	.....	12.99	28.3	28.9
	.....	.....	.....	.....	4	M. P.M. 2:15	53	2:46-3:46	2,217	2,628	0.88	.....	12.23	28.0	28.0
6/29	Child 10, M. Me., 5½ mos.	Positive von Piquet Normal weight	6,470	Formula P14;F30;OH66	6	P.M. 1:00 2:50	101	3:46-4:46	2,261	2,579	0.88	.....	12.45	28.0	28.3
	.....	.....	6,460	"	6	P.M. 1:00 2:50	101	3:16-4:17	3,278	3,336	0.93	1,428	16.32	28.2	28.7
	.....	.....	.....	.....	6	.....	101	4:17-5:17	3,150	3,912	0.92	.....	16.92	28.7	28.5
	.....	.....	.....	.....	6	.....	101	3:19-4:20	3,098	2,982	1.05	.....	14.54	28.2	28.8
	.....	.....	.....	.....	6	.....	101	4:20-5:20	3,150	3,912	0.81	.....	18.68	28.8	28.4

* Formula for this feeding was P25; F56; OH19.

the experiment was delayed to an hour and a quarter after feeding, the child woke fifteen minutes (Table 5) before the end of the first hour and, by restlessness, raised his metabolism more than 10 per cent.

From the respiratory quotient it would seem that in one case at least, Child 8 (C. D.), there must have been delayed absorption of the food. The earlier the first period started after the last feeding, the lower was the respiratory quotient; thus:

June 18, 19 minutes,	R. Q., .79
June 10, 33 minutes,	R. Q., .82
June 11, 1 hour 30 minutes,	R. Q., 1.00

The food throughout was the same in quality. Since absorption takes place from the stomach very slowly as compared with absorption from the intestine, the indications are that the delay took place at the pylorus. There were no clinical signs of a stenosis. The case seems, however, to illustrate the importance of meeting the same conditions of absorption on successive days. When such conditions are satisfactorily met (as, for example, with Children 1, 4, 6, etc.), one should get the same respiratory quotient in corresponding hours with the same child.

THE DYNAMIC EFFECT OF FOODS

Whether a diet of mother's milk or of cow's milk sufficient to maintain active growth in the child, exerts a dynamic action on the heat production is not yet clear from the published researches. Rubner and Heubner²² were of the opinion that they had demonstrated such an effect as regards cow's milk in their paper on the artificial nutrition of a normal and an atrophic infant. They estimated that a diet of cow's milk for the normal infant containing 44 per cent. more than the maintenance requirement raised the metabolism 9.7 per cent., while for the atrophic infant a diet containing 35.5 per cent. more than the requirement for maintenance raised the heat production 5.2 per cent. In a later paper²³ the same authors compared the metabolism of a breast-fed baby on full diet for four days with his metabolism on one day when he received only tea instead of the breast-milk. The metabolism on the day of starvation was even higher than the average of the four days on food. The experiment failed, therefore, to show any dynamic action of the food. This cannot be accepted as conclusive, however, for the reason that no graphic record of the child's activities was made. One would naturally expect a normal baby deprived of food to be more active than when well fed.

There can be scarcely any doubt that the child does respond to the dynamic action of the specific foodstuffs in much the same manner

22. Rubner and Heubner: *Ztschr. f. Biol.*, 1899, xxxviii, 315.

23. Rubner and Heubner: *Ztschr. f. exper. Path. u. Therap.*, 1905, i, 1.

as an adult. Howland⁹ was able to demonstrate an increase in the heat production of 10 per cent. by addition of 15 gm. of nutrose (5 gm. to each of three feedings) containing 14.25 per cent. nitrogen, in a child 3 months of age and an increase of 26 per cent. by addition of 30 gm. nutrose in another 7 months of age. A similar effect of increasing fat in the food was observed by Niemann²⁴ on a normal, though at the time, underweight, child 4 weeks of age by means of the Voit-Pettenkofer apparatus. In one period of four days when the food contained 127 calories from protein, 105 from fat and 168 from carbohydrate, or 400 calories in all, the average daily metabolism was 521 calories, or 1,337 calories per square meter per day. In the following period of five days the food contained 145 calories from protein, 368 from fat and 177 from carbohydrate, or 629 calories in all. The heat production in this period averaged 569 calories per day or 1,443 calories per square meter per day. An increase of 70 per cent. in the energy intake (largely fat) increased the metabolism 10 per cent. Niemann²⁵ observed a similar effect of increasing the fat in the food of an atrophic child 22 weeks old. Bahrdrdt and Edelstein²⁶ report an unusually high metabolism in an atrophic child fed on half milk with the addition of 5 per cent. milk-sugar, and express the opinion that this result, in contrast with the results of Rubner and Heubner and Niemann on atrophic children, was due to the high carbohydrate feeding. As already stated above, caution must be exercised in accepting any of these results obtained without a record of the child's activity or with one child as compared with another; but there is an evident possibility from the results cited that each and all of the foodstuffs may exercise a distinct dynamic action.

Frank and Wolff²⁷ have, apparently, confirmed on an extremely atrophic infant of 4½ months the interesting observation, first made by Rubner, that protein retained does not exert any specific dynamic action. In a period of three days when the food contained 102 calories from protein, 162 from fat and 166 from carbohydrate, 1.032 gm. nitrogen were retained daily and the child produced 1,581 calories per square meter per day. In a subsequent period of four days when the food contained 97 calories from protein, 139 from fat and 193 from carbohydrate, the nitrogen retention was 1.358 gm. per day and the heat production only 1,431 calories per square meter (Meeh) per day. This has been confirmed by one of us (H.) in collaboration

24. Niemann: *Jahrb. f. Kinderh.*, 1911, lxxiv, 650.

25. Niemann: *Festschrift z. Heubner*, Berlin, 1913, p. 467.

26. Bahrdrdt and Edelstein: *Festschrift z. Heubner*, Berlin, 1913, p. 1.

27. Frank and Wolff: *Jahrb. f. Kinderh.*, 1913, lxxviii, *Ergänzungsheft*, p. 1.

with Professor Lusk on the child L. of this series (results will be reported separately).

Notwithstanding the signs of dynamic action in all of this work, it has been found by Schlossmann and Murschauser and also by Howland that complete deprivation of food for from eighteen hours⁹ to forty-eight hours²⁸ does not lower the heat production of the child. Schlossmann and Murschauser kept a graphic record made by an eyewitness of the activity of their subjects. Benedict and Talbot¹⁰ also assert that in some instances the heat production (based on carbon dioxid) in their subjects twenty-one hours after food was "greater, even in periods of complete muscular repose," than immediately after food. In others, however, they were able to note an increase soon after feeding of from 5 to 10 per cent. above the heat production obtained from eighteen to twenty-one hours after.

While the weight of evidence from all of the previous work, therefore, is that the dynamic action of a sufficient dietary to keep the child growing actively is not very considerable, the effort has been made in this work to maintain such influence as the food may exert at an even level. Table 4 shows the distribution of the calories to the different organic constituents and the total amount received by the child at the last feeding before the respiration period.

In none of the experiments recorded here is the influence of food contrasted with complete inanition. In at least two of these, however, the dynamic influence of a large feeding as contrasted with a small one is plainly evident. Thus, Child 1 on February 28, had for clinical reasons been on a modified protein milk and received at 9 o'clock 223 calories of such milk. This was followed at 10:45 with an extra feeding of whole milk containing 148 calories. The respiration period started at 11:16, forty-six minutes after the last feeding. The child slept throughout the first hour but produced 12 per cent. more heat than he did on February 10, the corresponding hour following a single feeding of 148 calories in whole milk at 10:30.

Similarly, Child 2, because he had not previously slept more than one hour in the respiration chamber, was, on February 17, given two of his usual feedings only fifteen minutes apart. This time he slept nearly through the second hourly period, but produced two and a half calories per hour more than he had produced on February 14, when the feedings were two hours apart, or on February 16, when only one feeding, the regular one at 9 a. m., was given.

Since the two cases just mentioned represent the widest variations in the influence of different quantities of food in these experiments,

28. Schlossmann and Murschauser: *Biochem. Ztschr.*, 1913, lvi, 355, and lviii, 483; also Murschauser: *Boston Med. and Surg. Jour.*, 1914, clxxi, 185.

it is probable that the dynamic effect of the diets of the different subjects would not vary more than from 10 to 12 per cent.

With only one child (C. P.) was the food intentionally varied for the purpose of studying the effect of the change. After obtaining perfect duplicates on the high carbohydrate formula for two days, in the hope of benefiting his nutritive condition, he was placed for one day on a high fat formula (March 7). The result was a striking drop in the heat production. No clinical benefit appearing, he was next given a high protein formula for two days and on March 10 while still on this formula his metabolism was again studied. The nitrogen in the urine rose in response to the greater intake of protein and a significant rise in the heat production was found. The only difference in muscular activity in these periods was the greater number of the "readjustment movements" recorded on the "high protein" day (in Table 5). These brief and purely incidental results, so far as they go, are in accordance with the facts concerning the dynamic action of the foodstuffs in dogs established by Professor Lusk²⁹ and his co-workers in his (physiological) laboratory.

METABOLISM IN RELATION TO MUSCULAR ACTIVITY

Benedict and Talbot³⁰ as well as Schlossmann³¹ have properly emphasized recently the importance of recording as exactly as possible the degree of muscular activity in any study of the energy metabolism of infants. The experiments of this series have fulfilled this requirement fully. Examples of the graphic records obtained (see preceding description of methods, Figs. 1 and 2) are given in Figures 3 to 6.

In Table 5 is found a description of the child's condition of repose for each period. The abbreviation "r. m." or "read. mov." denotes the readjustment movements such as may be seen in Figure 3. When only these movements are mentioned it is to be understood that there are no others of any description visible on the records except the regular pulsations of the artery and the regular movements of the chest. Types of irregular respiration are seen in Figures 4 and 5.

RELATION OF METABOLISM TO PULSE-RATE

It is our belief that this relationship can easily be overestimated. Murlin and Greer³² have discussed this point fully and have attempted to analyze the factors involved, in a study of the relation of heart action to the respiratory metabolism of adult men and of anesthetized dogs. It was emphasized that the pulse-rate can be parallel to the respiratory

29. Jour. Biol. Chem., 1912, xii; several papers.

30. Benedict and Talbot: AM. JOUR. DIS. CHILD., 1912, iv, 129.

31. Schlossmann: AM. JOUR. DIS. CHILD., 1913, vi, 15.

32. Murlin and Greer: Am. Jour. Physiol., 1914, xxxiii, 253.

TABLE 5.—METABOLISM IN RELATION TO MUSCULAR ACTIVITY, PULSE AND RESPIRATION RATE, ARRANGED ACCORDING TO AGE

Date 1914	Name and Age	Period	Condition of Muscular Activity	Average Pulse-Rate	Average Resp. Rate	Calories per Hour	At This Rate Total Cal. Produced in 24 Hours	Total Cal. in Food in 24 Hrs.	At This Rate Per Cent. of Intake Consumed
2/13	A. Sa., 2 months	...	Sleeping throughout; 8 read. mov.	148	34	13.92	334	348	96
2/14	.....	I	Sleeping throughout; 5 read. mov.	133	Not Rec.	12.00	288	326	88
		II	Sleeping all but 10 minutes throughout; 5 read. mov.	147	....	15.42	370	...	114
2/16	.....	I	Two read. mov.; cried 10 min.	123	35	11.78	283	304	93
		II	Sleeping 21 min.; cried 40 min.	141	33	17.45	415	...	138
3/17	E. N., 3 months	I	Sleeping throughout; 3 read. mov.; resp. irregular	134	46	14.50	349	378	92
		II	Sleeping all but 15 minutes; cried four times	135	51	14.20	341	...	90
3/24	W. L., 2 months	I	Sleeping throughout; 7 read. mov.; resp. irregular	127	31	10.56	253	351	72
		II	Sleeping all but 18 min.; cried continuously 18 min.	131	37	13.09	314	...	89
3/25	.....	I	Sleeping throughout; 7 read. mov.; resp. irregular	118	29	10.74	258	324	80
		II	Sleeping all but 2 min.; cried just at end; 6 read. mov.	120	33	11.09	266	...	82
3/26	.....	I	Sleeping all but 1 min.; cried; resp. irregular	118	28	10.75	258	324	80
		II	Sleeping all but 4 min.; cried several times; resp. irregular	117	33	11.31	271	...	84
2/24	E. H., 2½ months	I	Moving (arms only) one-third of time; slept entire time	135*	42	12.68	304	409	74
		II	Slept entire time; restless ½ of hour	133	38.4	12.99	312	409	76
2/26	.....	I	Slept entire time; moving 3 min.; 4 read. mov.	131	41	12.23	294	409	72
		II	Slept entire time; 8 read. mov.	127	37	12.45	299	409	73
3/17	E. N., 3 months	I	Sleeping throughout; 5 read. mov.	112	25	10.87	261	337	77
		II	Sleeping throughout; 3 read. mov.	110	26	10.75	258	...	76
3/18	.....	I	Sleeping all but 10 min.; restless those 10 min.	132	39	10.53	252	337	75
		II	Sleeping 40 min.; fretted and cried 20 min.	126	34	12.04	289	...	86
3/19	.....	I	Sleeping throughout; 8 read. mov.	115	29	10.47	251	337	75
		II	Cried almost all the time	127	41	Leak			
2/27	C. P., 3 months	I	Sleeping throughout; 8 read. mov.; 8 long breaths	122	28	7.35	176	307	57
		II	Sleeping throughout; 4 read. mov.; 10 long breaths	130	27	7.15	171	...	56
3/ 3	.....	I	Sleeping throughout; 10 read. mov.; 5 long breaths	†	27	7.35	176	304	58
		II	Sleeping throughout; 15 read. mov.; 4 long breaths	....	26	7.43	178	...	59
3/ 7	.....	I	Sleeping throughout; 6 read. mov.; 5 long breaths	96	22	5.65	135	308	44
		II	Sleeping all but 2 min.; cried near end	99	24	6.37	153	...	50
3/10	.....	I	Sleeping throughout; 20 read. mov.	110	32	7.97	191	319	60
		II	Sleeping throughout; 35 read. mov.	110	29	8.27	198	...	62

* Pulse counted by stethoscope every five minutes.

† Pulse could not be counted.

TABLE 5.—(Continued)

Date 1914	Name and Age	Peri- od	Condition of Muscular Activity	Aver- age Pulse- Rate	Aver- age Resp. Rate	Calo- ries per Hour	At This Rate Total Cal. Pro- duced in 24 Hours	Total Cal. in Food in 24 Hrs.	At This Rate Per Cent. of Intake Consumed
6/10	C. D., 4 months	I	Moving all but 10 minutes	No Rec- ord	30.7	13.16	306	328	93
		II	Sleeping 39 min.; awake, play- ing, crying, fretting 21 min.		27.2	13.61	326	...	100
6/11	.....	I	Slept perfectly all through	No Rec- ord	24.5	9.26	222	328	68
		II	Moving all but 10 min.; cry- ing toward end		?	11.89	285	...	87
6/18	.....	I	Slept entire time; 10 read. mov.	103*	30	10.79	258	328	79
		II	Slept entire time; slightly restless	99	25.8	10.67	256	...	79
2/29	M. Me., 5½ mos.	I	Slept entire time; 5 read. mov.	143*	39	16.32	392	605	64
		II	Slept entire time; moving 4 min.	139	40	16.92	406	605	67
2/30	.....	I	Slept entire time; 3 read. mov.	138	39	14.54	349	605	57
		II	Slept entire time; 14 read. mov.	137	41	18.68	448	605	74
3/24	C. Ma., 10 months	I	Sleeping only 15 min.; moving hands—crying	118	46	26.54	637	775	82
3/25	.....	I	Sleeping only 10 min.; playing with hands and crying occa- sionally for 35 min.	114	41	24.50	588	555	106
		II	About same as P. I.	122	40	24.19	580	...	104
3/26	.....	I	Sleeping only 10 min.; playing with hands; cried hard at end	124	42	30.18	724	777	93
		II	Restless entire period; cried occasionally	128	43	27.24	654	...	84
		III	Lying still, playing with hands 15 min.; sleeping 45 min.	117	32	24.09	578	...	74
2/ 6	W. So., 11-12 mos.	I	Sleeping all but 5 minutes	†	....	26.50	636	770	83
2/10	.....	I	Sleeping throughout.....	112‡	....	23.88	573	770	74
		II	Sleeping 28 min.; awake but not crying 32 min.	?	....	26.45	635	...	82
2/11	.....	I	Sleeping throughout.....	115‡	....	23.51	564	770	73
		II	Sleeping throughout, but rest- less most of period	122‡	....	25.43	610	...	79
2/12	.....	I	Sleeping all but 15 min.; rest- less than 15 min.	123	42	26.23	629	450	140
		II	Sleeping only 10 min.; restless, but not crying, 50 min.	132	51	28.25	678	...	151
2/28	.....	I	Sleeping throughout; 6 read. mov.; resp. irregular	128	43	26.72	641	815	79
		II	Sleeping throughout but rest- lessly; 9 read. mov.; resp. irregular	No Rec- ord	48	27.75	667	...	82
3/21	J. Sm., 1 year	I	Restless and fretting more than two-thirds of period	118	41	20.74	498	462	108
		II	Sleeping all but 2 min. at beg.; 4 read. mov.	112	38	20.59	494	...	107
3/23	.....	I	Sleeping all but 10 min.; cried few times	112	36	19.73	474	481	99
		II	Fretted entire period.....	126	40	21.88	525	...	100

* Pulse counted by stethoscope every five minutes.

† Pulse could not be counted.

‡ Pith ball in blood-pressure app.

metabolism and the heat production only in case the volume output of the heart in different degrees of activity remains the same and the utilization of oxygen from the blood per heart-beat is the same. The same principles must obviously apply to the circulatory system of the child. Even in moderate degrees of activity produced by lifting a weight it was found in the work just cited that the product of the pulse-pressure³³ by the pulse-rate is a better criterion of the metabolism than is the pulse-rate alone.

That in greater variations of muscular activity the parallelism between pulse-rate and heat production does not hold for adults has been conclusively proven by Benedict and Cathcart³⁴ and more recently by Henderson and Prince.³⁵ Markwalder and Starling³⁶ using the heart-lung preparation of the dog have shown that when the pulse-rate is changed, e. g., from 72 to 156, the pulse-volume changes reciprocally, e. g., from 9.05 to 4.16 c.c. The total minute volume of blood-flow, however, remained the same.

With the same individual under the same conditions of food, temperature, etc., one would expect that minor fluctuations in muscular activity would be accompanied by fluctuations in the pulse-rate in the same direction, and this is borne out by a study of Table 5. As between children of different ages, where the pulse-rate for quiet sleep falls from 140 for a child of 2 months to 112 for a child of 12 months (Table 5), while the heat production nearly doubles, it is evident that the pulse-rate can be no criterion of metabolism.

The case of C. P. suggests the possibility of a relationship between the kind of food and the pulse-rate. This case has already been considered in connection with the dynamic action of the food. It may be seen from Table 5 that this child had a higher pulse-rate on a high carbohydrate food than on the high protein food which produced a greater dynamic action; while on the high fat formula both the pulse and metabolism were low.

The fourth column of Table 5 shows what the total metabolism in twenty-four hours would be if the same conditions of muscular activity, food, etc., continued for that length of time. It must be borne in mind that this way of expressing the metabolism is of doubtful value from the practical side and is adopted in this paper simply to serve as a basis of comparison between the results of this investigation and those of others. The plan adopted by Carpenter and

33. It was deemed impracticable in these experiments to obtain accurate readings of the pulse-pressure because of the risk of waking the child.

34. Benedict and Cathcart: Carnegie Institution of Washington, Pub. No. 187.

35. Henderson and Prince: *Am. Jour. Physiol.*, 1914, xxv, 106. The work of Murlin and Greer is incorrectly quoted in this paper.

36. Markwalder and Starling: *Jour. Physiol.*, 1914, viii, 348.

Murlin³⁷ and by Bailey and Murlin¹ of expressing the metabolism determined in hourly periods on the basis of an hour, whether dealing with a unit of weight or a unit of surface, is preferable.

From the last two columns in Table 5 may be seen what percentage of the total potential energy of the food in twenty-four hours would be utilized *in combustion* if the condition shown to the left of the table were to continue throughout. It may be of some interest practically to know that a child of, say, 2 months, fed 409 calories in twenty-four hours, utilized 74 per cent. of this energy (E. H.) for combustion alone even while sleeping, or that a child (J. S.) of 1 year (underweight) fed 462 gross calories is not getting food enough, if he is "restless and fretful more than two-thirds of the time," to support combustion alone.

METABOLISM IN RELATION TO SURFACE AREA

In order to have a satisfactory basis for comparison of the metabolism of the different children only the best sleeping periods (Table 6) have been selected, that is, those periods when sleep was either continuous throughout or was interrupted for only a few minutes. In one instance (C. M., March 26) the child, though awake for fifteen minutes of the period included, was lying very still, feeling drowsy and in reality in the process of falling asleep. The graphic records in these experiments made it possible to mark the very moment when a child fell asleep, or awoke.

The different formulas employed in the calculation of the surface area of children and their origin are too well known to require discussion at this time. Benedict and Talbot¹⁰ have covered the ground historically very recently. What remains is to discover *first* whether any such formula has any value in relation to the metabolism of children, and *second*, if so, which formula is best. It is not necessary to enter into a discussion as to whether one formula or the other best represents the actual surface area. That can be settled only by more actual measurements. Howland and Dana³⁸ have shown the range of variation of the fourteen actual measurements now on record. Applying these formulas and finding the average deviation from the mean of the actual metabolism in each instance, should enable us to judge which formula is of the greatest value as a criterion, whether it expresses the actual surface area or not. It is possible that the metabolism of the child exposed to a temperature of 27 to 29 C., at which chemical regulation does not enter (Rubner), is not at all proportional to the surface area, although there can be no doubt that

37. Carpenter and Murlin: Arch. Int. Med., 1911, vii, 184.

38. Howland and Dana: AM. JOUR. DIS. CHILD., 1913, vi, 33.

TABLE 6.—METABOLISM IN RELATION TO SURFACE AREA, ARRANGED ACCORDING TO AGE *

Name and Age	Condition	Date	Period	Weight, Gm.	Surface Area in Square Meters			Cal. per Hour	Calories per Square Meter and Hour				
					$11.9 \sqrt{(W)^2}$ (Meeh)	$10.3 \sqrt{(W)^2}$ (Lissauer)	$y=mx+b$ (Howland and Dana)		Calories per Square Meter and Hour				
									Meeh	Lissauer	Howland and Dana		
A. S., 2 mos.	Normal, over- weight	1914											
		2/14	I	5,810	0.384	0.333	0.354	12.00	31.2	36.03	33.90	864	813
		2/16	I	5,692	0.379	0.328	0.348	11.78	31.05	55.89	33.85	861	812
W. I., 2 mos.	Normal, near av. weight	2/17	I and II	5,690	0.379	0.328	0.348	14.35	37.38	43.72	41.23	1,050	989
		3/24	I	4,364	0.313	0.271	0.283	10.56	33.74	38.98	37.31	810	895
		3/25	I	4,371	0.318	0.275	0.294	10.74	33.76	37.82	37.82	810	907
E. H., 2½ mos.	Normal, aver- age weight	3/26	I	4,350	0.317	0.274	0.283	10.75	33.90	39.14	37.99	813	912
		6/24	I	4,690	0.339	0.287	0.299	12.68	38.03	43.94	42.41	1,055	1,018
		6/26	II	4,657	0.332	0.287	0.299	12.90	38.96	45.02	43.45	1,080	1,043
E. N., 3 mos.	Normal, un- derweight	6/26	II	4,657	0.332	0.287	0.299	12.23	36.95	42.57	40.90	984	982
			II					12.45	37.52	43.65	41.64	1,047	999
C. P., 3 mos.	Marasmus	3/17	I and II	4,115	0.305	0.264	0.272	10.81	35.38	40.87	39.74	849	953
		3/18	I	4,134	0.306	0.265	0.273	10.53	34.35	38.68	38.57	824	926
		3/19	I	4,147	0.307	0.266	0.273	10.47	34.88	40.30	39.25	887	942
C. D., 4 mos.	Normal, un- derweight	2/27	I and II	2,462	0.217	0.188	0.192	7.25	33.42	38.61	37.76	802	906
		3/ 3	I and II	2,515	0.220	0.190	0.195	7.39	33.58	38.80	37.90	805	909
M. M., 5½ mos.	Overweight; positive von Pirquet; no fever	6/11	I	3,375	0.268	0.231	0.256	9.265	34.58	39.96	39.24	880	942
		6/18	I	3,440	0.271	0.234	0.239	10.79	39.79	45.97	45.15	1,103	1,084
			II					10.87	38.45	45.46	44.64	923	1,072
C. M., 10½ mos.	Normal, over- weight	6/29	I	6,470	0.413	0.358	0.385	16.32	39.46	45.59	42.39	947	1,016
		6/30	II										
			I and II	6,460	0.412	0.357	0.385	16.92	40.91	48.27	43.95	981	1,053
W. S., 11-12 mos.	Normal, av- weight	3/25	I and II	9,382	0.529	0.458	0.526	16.61	40.24	46.49	43.14	966	1,034
		3/26	III	9,465	0.532	0.461	0.530	24.09	46.00	53.18	46.30	1,104	1,110
								45.24	1,086	1,255	45.45	1,255	1,091
J. S., 12 mos.	Normal, av- weight	2/10	I	9,373	0.529	0.457	0.526	23.88	45.14	52.15	45.40	1,083	1,090
		2/11	I	9,440	0.531	0.460	0.529	23.51	44.23	51.10	44.44	1,082	1,087
		2/28	I	9,555	0.536	0.464	0.534	26.72	49.87	57.59	50.03	1,197	1,201
J. S., 12 mos.	Normal (?), very much underweight	3/21	II	5,802	0.384	0.333	0.353	20.59	53.59	61.91	58.32	1,286	1,400
		3/23	I	5,713	0.380	0.329	0.349	19.78	52.02	60.10	56.08	1,249	1,360
Mean					38.84	44.85	42.20						
Mean, omitting J. S.					37.96	43.90	38.82						
Average deviation from mean, omitting J. S.					+3.81	+4.96	+3.52 or						
Algebraic mean					-0.03%	-11.3%	9.04%						
					-0.059	-0.58	+2.43						

* Only best sleeping periods are included.

the metabolism of the child as compared with the adult is much more nearly proportional to Meeh's formula than to the body weight.³⁷

The abnormally high metabolism of Child J. S. (Case 5) seems to justify his exclusion from this comparison on the suspicion that

Fig. 7.—Showing relation of heat production to skin surface according to Meeh's formula. Authors' ten cases.

his trouble may have been due to hyperthyroidism. The mean metabolism of the nine remaining children based on the actual hourly determinations while the children slept, soon after feeding, and cal-

culated to the square meter basis is as follows: 37.96 calories for Meeh's formula; 43.90 calories for Lissauer's and 38.82 calories for Howland and Dana's equation. The mean deviation from this mean for the thirty-two hourly periods is ± 3.81 Cal., or 10.03 per cent. for Meeh's formula; ± 4.96 Cal., or 11.3 per cent. for Lissauer's and ± 3.52 Cal., or 9.04 per cent. for Howland and Dana's. For all of these formulas, therefore, the mean deviation from the mean is in the neighborhood of 10 per cent. The extreme deviations, however, are much greater (Table 6) namely: -6.91 to $+11.41$ calories per square meter, or -18.2 per cent. to $+31.4$ per cent. for Meeh's; -8.02 to $+13.6$ calories or -18.3 per cent. to $+31.2$ per cent. for Lissauer's; and -4.97 to $+11.21$ calories or -12.8 per cent. to $+28.9$ per cent. for Howland and Dana's. On both counts the equation of Howland and Dana lies a little nearer the actual facts of metabolism than the others.

The algebraic mean, however, for the present series of observations throws the favor to Meeh's formula. This lies at $-.059$ calories or very near the zero point; for Lissauer's it lies at -0.58 calories and for Howland and Dana's at $+2.43$ calories. It is a curious coincidence that an equation so constructed as to give a "gross error" (algebraic deviation from the mean) of zero, as an expression of the actual surface areas as found, should give, when used as a unit for the actual metabolism, the largest algebraic deviation. This but emphasizes the inference that the metabolism for this series of children, at least, is not very closely parallel to the surface area as found by the existing measurements. Nothing more should be deduced from the data here presented. The entire discrepancy may possibly be explained by the fact that the majority of the actual measurements were made on atrophic or underweight children,³⁹ while only three out of the nine children here averaged were underweight.

The conclusion of the inquiry in connection with the surface area, so far as these observations go, is (1) that the mean deviation from the arithmetical mean (probably the best criterion of the worth of a formula) is least with the equation of Howland and Dana, but (2) that with Meeh's formula the algebraic mean lies nearest the zero point.

A graphic representation of the metabolism in relation to surface area according to Meeh's formula is shown in Figure 7. The distribution would be essentially the same for either of the other formulas. The position of each child on the chart represents calories per square meter per hour. The diagonal line represents approximately the mean for the ten children. It is evident at a glance that the older children have the higher metabolism per unit of surface. The only cases which

39. Benedict and Talbot: Carnegie Pub. No. 201, table, p. 164.

do not exceed the resting metabolism of a healthy adult are the atrophic child C. P., 3 months, and the normal boy W. L., 3 months; C. D. (underweight) at 4 months of age has a metabolism of 37.60 calories; M. M., at nearly 6 months, a metabolism of 40; the girl C. M. at 10½ months a metabolism of 45.7 and W. S. at 12 months a metabolism of 46.4 calories per square meter and hour. This is brought out clearly in Table 7, arranged according to age.

TABLE 7.—SUMMARY OF SLEEPING PERIODS, SHOWING RELATION OF HEAT PRODUCTION TO BODY WEIGHT AND SURFACE AREA (MEEH)

Name	Nutritive Condition	Age, Months	Average Net Weight, Gm.	Cal. Per Hour	No. of Periods Averaged	Calories Per Kg. and Hour	Cal. Per Sq. Meter (Meeh) and Hour
A. Sa.	Normal; overweight	2	5,730	13.16	4	2.30	34.73
W. L.	Normal; slightly below aver. weight	2	4,362	10.68	3	2.45	33.80
E. H.	Normal; av. weight	2½	4,673	12.58	4	2.71	37.84
E. N.	Normal; underweight	3	4,132	10.65	4	2.59	34.99
C. P.	Atrophic	3	2,488	7.32	4	2.94	33.50
C. D.	Normal; underweight	4	3,410	10.24	3	3.00	37.60
M. Me.	Normal; (?) positive v. Pirquet; av. wt.	5¾	6,456	16.62	4	2.56	40.21
C. Ma.	Normal; overweight	10½	9,424	24.26	3	2.49	45.74
W. So.	Normal; av. weight	11½-12	9,456	24.70	3	2.51	46.41
J. Sm.	Normal (?); very much underweight	12	5,757	20.16	2	3.51	52.80
Mean of all cases.....						2.75	39.76
Mean omitting J. S.						2.63	33.31
Mean deviation						0.163 (6.2%)	3.87 (10.1%)

Any difference in the dynamic action of the food (richer in carbohydrates) given to the younger children as compared with that (richer in protein and fat) given to the older children would favor the younger, that is, the dynamic action of the carbohydrate (probably) would be greater. On the other hand, the older children, C. M. and W. S., were a little more restless than the younger (Table 5). These two sources of possible discrepancy would tend to neutralize each other, and it is therefore clear that the recently fed, healthy, growing child at 1 year of age has, while asleep, a heat production considerably higher per unit of surface than that of a child up to 6 months, or than that of the adult; while the child from 2 to 4 months of age has a metabolism per unit of surface about the same as that of the adult⁴⁰ (1) (34 calories per square meter per hour).

40. Cf. Carpenter and Murlin: Note 37. McCrudden and Lusk: Jour. Biol. Chem., 1913, xiii, 447. Du Bois, Eugene F.: The Total Energy Requirement in Disease as Determined by Calorimetric Observations, Jour. Am. Med. Assn., Sept. 5, 1914, p. 827.

Benedict and Talbot⁴¹ express the opinion that age is not a determining factor and yet they present a table of six normal infants in which there is a clear difference between infants under 6 months and those over 6 months. In another table (page 167) they compare the metabolism of infants of different ages but of the same weight and height, showing that in every instance the older child has the higher metabolism. Their explanation is that the older infant has a deficiency of fat and therefore a greater proportion of active protoplasmic tissue. We have seen, however, that fat does not replace active protoplasm (the nitrogen content of the body must be taken as a measure of the mass of protoplasm), but replaces water. Benedict and Talbot's table could therefore be used equally well to prove that the older infant, within the range from 2 months to 12 months, has a specifically higher coefficient of metabolism, or else has the same coefficient and the heat production is greater because the heat loss is greater.

We have calculated the heat production of all of Benedict and Talbot's normal infants of average weight, or nearly so, as given in their longer table⁴² to the basis of a square meter and hour and have

TABLE 8.—CALORIES PER SQUARE METER PER HOUR

2 Months		3 Months		4 Months		6 Months		7 Months		9 Months		10-11 Months		12 Months	
B. D.	33.3	E. F.	29.5	L. R. B.	35.2	M. M.	40.2	P. W.	41.6	R. L.	41.3	E. A.	37.8	W. S.	46.4
F. D.	37.3	A. S.	32.2	M. C.	35.3					R. S.	40.2	C. M.	45.7		
L. L.	31.7	E. R.	36.4	R. E.	38.3										
W. L.*	33.8	E. N.	34.9	D. O.	35.2										
E. H.	37.8														
A. S.	34.7														

* Benedict and Talbot's cases light face. Authors' cases full-faced type.

compared them with the normals of the present series with the result shown in Table 8.

The average of the fourteen cases up to and including 4 months of age is 35.4 calories per square meter and hour; the average of the seven cases from 6 months to 12 months inclusive is 41.9 calories per square meter and hour. The mean deviation in the first group is 5.4 per cent.; in the second group 5.7 per cent. There is some indication that the increase is a progressive one with increasing age; but the decision of this important matter must wait on further observations.

41. Benedict and Talbot: Carnegie Institution of Washington, Pub. No. 201, p. 165.

42. Benedict and Talbot: AM. JOUR. DIS. CHILD., 1914, viii, 1.

METABOLISM IN RELATION TO BODY WEIGHT

Figure 8 represents on the same scale as Figure 7 the heat production per kilogram and hour. The diagonal in this case (2.5 calories per kilogram and hour) is not quite the mean of all cases (Table 7), but is chosen as a convenient reference line. That the heat production in this series of ten children between the ages of 2 months and 12 months and varying in nutritive condition from extreme atrophy to extreme fatness, is more nearly proportional to weight than to surface area is seen from Table 7. Omitting J. S., the mean deviation from the mean (2.63 calories per hour), on the basis of weight is 6.2 per cent.; while on the basis of surface it is 10.4 per cent.

One must be on guard here against the hasty conclusion that metabolism in general is more nearly proportional to weight than to surface area. Taking the entire group of nine children this is unquestionably true "on the face of the returns." It would not be true, however, as regards any group of the same age. It has been seen that the average heat production of children above 6 months of age is higher, on the basis of a unit of surface, than is that of children ranging from 2 to 4 months, inclusive. It will be interesting now to make the same comparison on the basis of weight (Table 9).

TABLE 9.—CALORIES PER KILOGRAM AND HOUR

2 Months		3 Months		4 Months		6 Months		7 Months		9 Months		10-11 Months		12 Months	
B. D.	2.33	E. F.	1.84	L. R. B.	2.30	M. M.	2.56	P. W.	2.57	R. L.	2.50	E. L.	2.13	W. S.	2.61
E. D.	2.63	A. S.	2.11	M. C.	2.23					R. S.	2.22	C. M.	2.56		
L. L.	2.18	E. R.	2.63	R. E.	2.67										
W. L.*	2.45	E. N.	2.59	D. O.	2.40										
E. H.	2.71														
A. S.	2.30														

* Benedict and Talbot's cases light-faced type. Authors' cases full-faced type.

The average for the group of fourteen younger infants is 2.38 calories per kilogram and hour, with a mean deviation from this of 0.19 calorie or 8 per cent. The average for the group of older infants is 2.45 calories with a mean deviation of 0.159 calorie, or 6.5 per cent. The percentage deviation being greater in both groups on the basis of weight than on the basis of surface, it follows that the metabolism in both is more nearly proportional to surface. Incidentally also it is clear that even on the basis of weight the metabolism of the older infants is somewhat greater than that of the younger.

SUMMARY OF ALL REPORTED CASES

Figure 9 exhibits the variations in the heat production per unit of weight of all the children whose metabolism has been determined by the indirect method of Voit and Pettenkofer or according to the prin-

Fig. 8.—Showing relations of heat production to bodyweight, and effect of using “approximate specific gravity.” Authors’ ten cases. The plain circles represent the number of calories per kilogram and hour; the starred circles represent the same after first correcting the weight by multiplying by the approximate specific gravity. See, however, Note 12.

Fig. 9.—Showing relation of heat production to body weight. All infants whose metabolism has been studied by von Pettenkofer or Regnault-Reisch methods.

ciple of Regnault and Reiset. Figure 10 exhibits the heat production for the same cases on the basis of a unit of surface according to Meeh's formula. In both charts the atrophic or underweight infants are designated by a dot; thus, $\odot$ or $\bullet$; those of normal weight by a cross $\otimes$, $\boxtimes$, etc., and the overweight infants by a cross thus, $\oplus$, $\boxplus$, etc. In Figure 9 it may be seen that with but three exceptions (all in Benedict and Talbot's series) the heat production of the atrophic or underweight infants is above 2.5 calories per kilogram per hour; the normals lie close to this line and the overweights with a single exception (C. M. of our series) lie below the line. Properly speaking, only the infants whose heat production has been measured while sleeping (those of Howland, Benedict and Talbot and ours) are comparable. The mean for all the infants between the ages of 2 months and 1 year comprised in this way (sixty-one in all) is 2.7 calories per kilogram an hour. The average deviation from this mean among the sixty-one infants is 0.326 calories, or 12.1 per cent. The mean for the same list of infants on the basis of a square meter of surface (Meeh) is 39.3 calories per hour; while the average deviation from this mean is 4.34 calories or 11 per cent. Taking all the American infants within the range of from 2 to 12 months studied while sleeping, therefore, the heat production is slightly more uniform on the basis of Meeh's formula than on the basis of weight.

DISCUSSION

Judging by the comparison contained in these charts as well as by the summary of Bahrtdt and Edelstein²⁶ there is a considerable discrepancy in the application of the law of surface area to children of different age and different nutritive condition. Benedict and Talbot⁴² having before them all of the data, save those from the ten cases of the present series, reached the rather sweeping conclusion that there is no correlation between the heat production and the surface area. Such a conclusion is not, however, justified by the facts; for an average variability of ± 10 per cent. is not so excessive as biological laws go.⁴³

43. One reason why the charts of Benedict and Talbot seem to show "absolutely no correlation" either between body weight and heat production or skin surface and heat production is the fact that the zero point for only one variable is shown. Another reason is the duplication of ordinates. For example, when one compares the body weight as ordinates with the calories per kilogram and twenty-four hours as abscissae, there is a duplication of weight in both variables. The better way to plot such results is to choose two supposedly independent variables as ordinates and abscissae having a common zero point. Still further, if Benedict and Talbot had distinguished in their chart the atrophic or underweight children from the normal and overweight cases, they would have discovered the interesting facts mentioned under "Summary of All Reported Cases."

Fig. 10.—Showing relation of heat production to skin surface. All infants whose metabolism has been studied by von Pettenkofer or Regnault-Reisch methods.

Curiously enough, these authors appear to regard their findings on infants as a crucial test of the law of surface area; whereas the conditions necessary for its proof, recognized by Rubner⁴⁴ from the first, have not been (and could not be with the material selected) complied with. Rubner has always recognized the fact that the proof of the law of surface area requires similar physiologic conditions. Speaking of its applicability to children in 1906, he⁴⁵ says:

“Das Oberflächengesetz gilt unter allen physiologischen Lebensbedingungen: In seinem Beweise ist aber sinngemässe Voraussetzung, dass nur Organismen mit gleichartigen physiologischen Leistungen, was Ernährung, klimatische Einflüsse, Temperament und Arbeitsleistung betrifft, verglichen werden.”

Rubner has never yet admitted that age is a variable factor in its influence on metabolism. But from the results presented by Benedict and Talbot and by Bailey and Murlin¹ on new-born infants, the differences cited in Table 7 and those recorded by Rubner himself, by Sondén and Tigerstedt, Magnus-Levy and Falk and McCrudden and Lusk, it is impossible not to see a functional variation with age.

The general law of surface area as applied to animals of the same species but different weight rests on a very secure observational foundation.⁴⁶ Whether it can be said also to apply uniformly to the entire class of mammals is doubtful.⁴⁷ Specific differences in the influence of certain organs such as the thyroid, differences in coat covering, proportion of parts, rate of growth, etc., probably must be reckoned with. What remains to be discovered in the application of the law to the human species is the cause of the discrepancies, and it is to this question that the present inquiry has been directed.

The specific question which we have been concerned with is the influence of body fat. The presence of fat always reduces the metabolism per unit of weight and, according to Meeh's formula, it frequently reduces the metabolism per unit of surface; while its absence produces the opposite effects. At the beginning of this investigation we supposed that fat in general is merely added to the protein, that is, active protoplasm, and it was for this reason that an effort was made to employ the specific gravity as a measure of the proportion

44. Rubner: *Ztschr. f. Biol.*, 1885, xxi, 337.

45. Rubner: *Arch. f. Hyg.*, 1906, lxvi, 89.

46. Cf. e. g. Rubner: *Ztschr. f. Biol.*, 1885, xxi, 337, Sondén and Tigerstedt: *Skand. Arch. f. Physiol.*, 1895, vi, 1. Magnus-Levy and Falk: *Arch. f. Anat. u. Physiol.*, 1899, Phys. Abt. Suppl., p. 314. Slowtsoff: *Pfluger's Arch. f. d. ges. Physiol.*, 1903, xcv, 158. Kettner: *Arch. f. Anat. u. Physiol.*, Phys. Abt., 1909, p. 447. Carpenter and Murlin: *Arch. Int. Med.*, 1911, vii, 184. Hill and Hill: *Jour. Physiol.*, 1913, xlvi, 81. Du Bois: *Jour. Am. Med. Assn.*, Sept. 5, 1914, p. 827.

47. Pütter: *Ztschr. f. allg. Physiol.*, 1911, xii, 125.

between the two. Before the work was completed, however, it became clear from the analyses of infants of widely different nutritive condition, reported by Ohlmüller, Sommerfeld, Steinitz, and Steinitz and Weigert that fat replaces water; hence, the specific gravity, even could it be determined accurately, could not give a measure of the proportion between active and inactive tissue. This test, therefore, fails completely; for although the volume of the body as found by Kastner's method does appear to have an inverse relation to the heat production, it probably is not because of the proportion of fat present (see Figure 9).

Evidence has been presented that the metabolism increases from birth up at least to 1 year of age. The difference in nitrogen content between the new-born and infants from 2 to 4 months of age (Table 1) is due in part to loss of water; hence it seems possible that the coincident increase in metabolism may be explained by a loss of water and gain in the activity of the protoplasm. But the constancy of the protein content between children of the same age (nearly) but of different nutritive condition seems to make it clear that the proportion of active protoplasm as compared with fat cannot be the cause of the observed discrepancies between thin and fat children. What better criterion of protoplasmic mass could be had than protein content of the body? If this point is well taken, then the presence of fat must operate in one of two ways: either it affects the heat production by reducing the quality of the active protoplasm, or it affects merely the heat loss.

SUMMARY

1. Ten infants ranging in age from 2 months to 12 months and in nutritive condition from the last stage of marasmus to considerably overweight, have been compared as to their heat production both on the basis of weight and of surface area.
2. The heat production was calculated from the oxygen absorption with knowledge of the respiratory quotient (corrections being made for temperature, barometric pressure, and composition of the air) and from the nitrogen of the urine.
3. Graphic records of the respiration (in all cases) and of the pulse (in all but three cases) were obtained, these recording devices serving also to exhibit plainly on a smoked paper the degree of quiescence of the subject.
4. The approximate specific gravity was determined by Kastner's method in the hope that it might serve as a measure of the proportion of fat to active tissue.

5. The child was fed immediately before the observation each day and in nearly every experiment slept at least one, often two hours, while the respiratory exchange was being measured.

CONCLUSIONS

1. The specific gravity, even if accurately measured, cannot serve as a measure of the proportion of fat to active tissue, because, according to the analyses of Sommerfeld, Steinitz, and Steinitz and Weigert the fat replaces only water, the nitrogen remaining constant for children of widely different nutritive condition and nearly the same age.

2. The heat production for the sleeping period averages for the ten children 2.7 calories per kilogram and hour. It is highest on this basis for the atrophic and underweight children and lowest for the fattest child.

3. On the basis of a square meter of surface the heat production of normal children shows a decided increase from the early months (2-4) to the later months (6-12) of the first year. The average of all the ten children is 39.7 calories.

4. The average deviation from the mean heat production in all sleeping periods is about ± 10 per cent. for each of the several formulas expressing the relation of surface area to weight (Meeh, Lissauer, Howland and Dana). The algebraic mean deviation is least with the formula of Meeh.

5. Almost identically the same average heat production per unit of weight and per unit of surface is obtained when all the infants between 2 months and 12 months in Howland's, Benedict and Talbot's and our series (sixty-one in all) are compared, i. e., 2.7 calories per kilo and hour, 39.3 calories per square meter and hour (Meeh). On the unit of weight all but three of the atrophic and underweight children (forty-eight in all) lie above the line represented by 2.5 calories per kilogram and hour; all the normals (eighteen) lie near this line; and all but one of the overweight infants (five) lie below the line. Two and one-half calories per kilogram and hour or 60 calories per kilogram and twenty-four hours may therefore be called tentatively the "normal heat production" of recently fed, sleeping infants between 2 months and 1 year of age. Included in this figure is whatever dynamic action the foods themselves may have; otherwise the figure is minimal. Hard crying may increase the metabolism as much as 40 per cent.; the requirement for growth and an allowance for non-absorption must be added.

6. The average deviation from the mean on the basis of weight for all these children is 12.1 per cent.; on the basis of surface area (Meeh) 11 per cent. For smaller age groups of normal children the deviation is considerably less on the basis of surface area than on the basis of weight. Taking into account possible variations in the dynamic influence of food, these results must be regarded as confirmatory of the "law" of surface area of Rubner.

7. There seems to be no sufficient reason, however, for estimating the food requirements of infants on the basis of surface area rather than on the basis of weight.