THE CALORIC REQUIREMENTS OF NORMAL INFANTS AND CHILDREN FROM BIRTH TO PUBERTY

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During the past eight years Dr. Francis G. Benedict and I have been conducting a series of studies at the Nutrition Laboratory of the Carnegie Institution of Washington on the energy metabolism of normal infants and children from birth to puberty. A preliminary report of these investigations was recently given by Dr. Benedict in the Shattuck Lecture delivered before the Massachusetts Medical Society at Boston, June 3, 1919.¹ The detailed report of these observations will be published later in a publication of the Carnegie Institution of Washington and will contain a review of the literature of the metabolism of normal infants and children, and a complete discussion of the normality of the subjects studied. In this series of investigations we included 108 boys and 70 girls. The majority of the younger subjects were normal breast-fed infants. These were studied at the Boston Directory for Wet-Nurses. The older subjects were selected from the New England Home for Little Wanderers, all possible efforts being directed towards individuals who represented normality.

Photographs are shown and a description of the apparatus and technic used in these investigations is given in detail in the article by Benedict.¹

Chart 1 gives the total basal metabolism for twenty-four hours of normal children from birth to puberty. In this instance the calories are plotted against age, showing that the total calories become larger as the age increases. By "basal metabolism" is meant the minimum metabolism necessary to maintain life with the patient at complete muscular repose, and, if possible, without any food in the stomach. It was impossible, however, to study the younger subjects without food. The older subjects were studied in nearly all instances without food.

Chart 1 shows that there is no difference between the basal metabolism of boys and girls up to about one year of age, or about 10 kg. of weight, after which there is a sex differentiation, boys of the same weight having a somewhat higher metabolism than girls of the same weight until they reach 34 kg. of body weight, when the metabolism

1. Benedict, F. G.: Boston M. & S. J. **181**:107 (July 31) 1919.

of both sexes is the same, after which the basal metabolism of girls is somewhat higher than that of boys.

If the basal metabolism shown in Chart 1 were doubled it would approximate the total calories that a child of a given weight would require. This, however, is not quite accurate because the growth factor is greater during the first year of life than it is during later childhood. It is necessary, therefore, to a little more than double the basal metabolism before the age of six months in order to obtain the total metabolism, whereas, after six months of age, doubling the basal metabolism more than gives the total number of calories that are necessary for a child to grow. Whether these figures will be sufficient

will depend upon the habits of the child, as shown by Captain Gephart at St. Paul's School in Concord, N. H., in which he found that the average intake in food in his subjects was 5,000 calories per day.²

Chart 2 gives the measured total basal metabolism of infants from birth to one year, and at the same time estimated curves showing the weight, food intake and available food.

The lower line on Chart 2 represents the total basal metabolism, which, at six months, is 400 calories. This does not mean, however, that all normal children have a basal metabolism of 400 calories at six months of age, since some infants grow much more rapidly and attain a greater length and weight than other infants of the same age.

2. Gephart, F. C.: Boston M. & S. J. **176**:17 (Jan. 4) 1917.

Infants with a greater weight than the average tend to have a higher basal metabolism than the curve given here, while normal infants with less weight than the average usually have a slightly lower basal metabolism.

The upper curve represents the normal increase in body weight of an average infant from birth to one year, and shows the initial loss of

weight which occurs during the first three days of life, before the breast milk "comes in."

The heavy line to which the arrow points indicates the intake of breast milk, which commences about the third day and represents on an average the total calories normally received about this time. This rises rapidly after a sufficient amount of breast milk calories are sup-

plied for the infant to gain in weight. This curve, representing the number of calories in the breast milk, is estimated from figures found in literature. The total number of calories supplied in the food in this manner naturally vary with the different nursing mothers, and are influenced both by the quality and quantity of the milk. It may be

Chart 3

assumed generally that at the end of the first month a baby will be receiving, on an average, approximately 500 calories a day, and at the end of the ninth month about 880 calories a day.

It has been estimated that about 90 per cent. of the food taken by an infant is available for use in the body, the balance being lost in the excreta. Taking this as a standard, the curve in Chart 2 represented

by long dashes gives the available energy which an infant may use at a given age. For example, at six months about 785 calories are ingested, about 705 of these calories being available for use in the body, the remaining eighty calories having been lost in the excreta.

It has been shown by other investigators as well as ourselves, that muscular activity increases the metabolism. We have shown that in

new-born infants crying and kicking may increase the metabolism as much as 200 per cent. for a short time. To estimate the energy used up by muscular activity throughout an entire day, continuous direct measurements are necessary. This was done in two normal infants previously reported by Talbot.³ In one of these infants the increase

3. Talbot, F. B.: *Am. J. Dis. Child.* **14**:25 (July) 1917.

in metabolism throughout the twenty-four hours was 30 per cent., and in the other 20 per cent., over the basal metabolism. It may be assumed, therefore, until further figures are obtained, that the average increase of metabolism, due to muscular exercise, over the basal metabolism in a normal infant is 25 per cent. This percentage was, therefore, added to the basal metabolism and is represented in Chart 2 by the

short dashes, and shows that at six months the basal metabolism of an infant is 400 calories with 100 more calories used up during the day in muscular activity. This figure, however, can only be taken as the average amount, since it cannot be assumed that all infants have the same amount of muscular activity.

The greatest rate of growth is during the first five to six months of life when an infant doubles its birth weight. During the second six months of life, the gain in weight is approximately the same as during the first five or six months, but, whereas, the increase in weight was 100 per cent. in the first six months of life, it is in the neighborhood of 50 per cent. in the second six months. Since the period of

greatest growth is during the first year of life, relatively more food must be available for growth during this period than at any other time. It is obvious that the rate of growth is affected by the number of available calories. In Chart 2 the space between the lines of short and long dashes represents approximately the amount of food which goes for growth. According to the figures on this chart, which, it

must be remembered, are only estimations, 36 per cent. of the food intake went for growth at three months; 26 per cent. at six months, and 21 per cent. at nine months. According to Cammerer,⁴ only 15 per cent. of the food energy was retained for growth, while Rubner and Heubner⁵ found it to be 12.2 per cent.

In Chart 3 is shown the hypothetical effect of a diminished food supply on growth.

According to Chart 3, an infant received sufficient breast milk for growth up to four months of age, to the point marked *a*, at which time the breast milk began to give out. During the course of the next three months the milk continued to diminish very rapidly, but the mother was unwilling to give a supplementary bottle feeding. At the point marked *b* it is seen that the available energy just equals the calories extended by the basal metabolism and the muscular activity of the infant, and that nothing is left for growth. At this point the infant's weight is stationary. Between the points marked *b* and *c* the available energy is less than the amount used up by the infant in its basal metabolism and muscular activity. At this period the infant must obtain its food from some other source, and does so by using up its body tissue, thus losing in weight from 6 to 5 kg. Presumably, this is done at the expense of its own body fat.⁶ At the point marked *c* the condition of the infant becomes so serious that the parents are willing to consult a physician and have a supplementary bottle feeding given. Enough calories are then added to bring the total food up to the normal requirements for growth, the infant gains rapidly, and after enough food is given and properly digested, it reaches the average weight for its age in a short time. Osborne and Mendel⁷ have shown by their observations on white rats that it is possible to resume growth after long continued failure to grow.

Chart 4 shows the hypothetical effect of diarrhea on growth.

The recent work of Holt and his co-workers⁸ shows that a great deal of fat is lost in the stools during diarrhea. Normally, 91.3 per cent. of the fat in the food is retained in the body, while in diarrhea only 79.3 per cent., and in severe diarrheas only 58.5 per cent. is retained. There is a corresponding loss of protein when casein curds

4. Cammerer: See Lusk, *The Science of Nutrition*, Ed. 3, Philadelphia and London, W. B. Saunders & Co., 1917, p. 412.

5. Rubner and Heubner: See Lusk, *The Science of Nutrition*, Ed. 3, Philadelphia and London, W. B. Saunders & Co., 1917, p. 412.

6. Benedict, F. G., and Talbot, F. B.: *The Physiology of the New-Born Infant*, Carnegie Institution of Washington, Publication No. 233.

7. Osborne, O. T., and Mendel, L. B.: *J. Biol. Chem.* **22**:439 (Sept.) 1915.

8. Holt, L. E., Courtney, A. M., and Fales, H. M.: *Am. J. Dis. Child.* **17**: 423 (May) 1919.

are found in the stools. In one instance noted by Talbot and Gamble,⁹ 24 per cent. of the ingested nitrogen was lost in the stools.

In Chart 4 it may be assumed that at the point marked *a* an infant commences to have diarrhea, and, as a consequence, there is a great increase in the number of calories lost in the stools, as shown by the chart, with the usual loss in appetite. The available energy is then reduced to such an extent that the infant has nothing left for growth and stops gaining. If the infant becomes restless, and the muscular activity increases, more than 25 per cent. more calories will be burnt up than are available for use, and the infant will lose weight. At the point marked *b* the diarrhea stops, there is no longer excessive loss of energy in the stools, and growth is resumed.

Chart 5 shows the hypothetical effect of fever on growth.

It has been shown that a rise in body temperature increases the metabolism.¹⁰ In Chart 5 it may be assumed that an infant becomes feverish at the point marked *a*, and there is an increase in the basal metabolism. Associated with fever is nearly always an increase in muscular activity and restlessness due to discomfort, with a loss of appetite and consequent drop in the caloric intake. This is shown on the graphic chart and the result is that during fever there is no food left for growth. If the available energy becomes less than the energy used up by the basal metabolism plus the muscular activity the child loses weight.

Chart 6 shows the hypothetical effect of muscular activity on growth.

Northrup¹¹ reported several cases of infants with nervous prostration in which there was excessive muscular activity due to prolonged mental stimulation. Such infants are continuously on the "*qui vive*," are very active with the slightest provocation, sleep less than the normal, and practically always lose their appetite. The effect of excessive muscular activity on growth in such cases is illustrated in Chart 6. It also pictures what happens to the older child who over-exercises and runs himself "as thin as a rail."

Chart 1 and the lower line on Chart 2, representing the basal metabolism, are the results of actual measurements of the metabolism of normal infants and children. The remaining curves on Chart 2 and Charts 3, 4, 5 and 6 were plotted merely to give a graphic picture of characteristic cases. They do not represent cases actually measured in real life.

9. Talbot, F. B., and Gamble, J. L.: *Am. J. Dis. Child* **12**:333 (Oct.) 1916.

10. Lusk: *Loc. cit.*, p. 499.

11. Northrup: *Arch. Pediat.* **22**:14, 1905.