THE FUNDAMENTAL REQUIREMENTS OF AN INFANT'S NUTRITION *

JOHN HOWLAND, M.D.
ST. LOUIS

The requirements for an adult's nutrition under the most varying circumstances are definitely known. The amount of food that is necessary to keep him in a state of equilibrium when at rest, when exercising moderately and when undergoing the most violent exertions, has been determined with scientific accuracy. These determinations may be repeated as often as wished, and, provided they are properly made, will give uniform results. They are laborious and time-consuming, but yield trustworthy data because, with the assent and the cooperation of the adult subject, the conditions can be absolutely controlled.

It is not so with children or infants. There is no reason to believe that in them the laws of nutrition differ in any marked way from those of the adult, but the control of conditions so as to make our results trustworthy is extremely difficult, and we are able to obtain, at best, only a part of the information that we wish, accurate though this be. I shall speak of this more fully later, because it is the one, and apparently the only, insurmountable obstacle in the way of the most scientific and satisfactory accuracy in determining the food requirements of the infant.

There are certain fundamental facts that must be considered in dealing with this subject. The warm blooded animal requires energy for the life processes of the organism, the heart-beat and circulation, the respiration and the activity of the various organs and glands, and the heat produced by these processes, with the assistance of the physical vasomotor control, maintains the cells at their normal tropical temperature, in which they functionate to the best advantage. Energy is also required in addition for the animal's endless muscular activities. The energy that the body expends is all given off and may be measured as heat—all except that energy contained in substances in the urine and feces that have failed of complete combustion and which for the present may be disregarded. It is therefore quite logical to speak of the energy expended in terms of heat-units and of the food that is ingested to furnish this energy and which is readily converted into it, in the same terms.

If the output is known, the human body may be retained in a state of equilibrium by furnishing an amount of energy in the form of food

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equal to this, and, as I have said, the output is, especially in adults, capable of being measured. It is obviously impossible to do this for each patient that must be fed, but Rubner's work makes this no longer necessary. Pettenkofer and Voit measured the output of different men under the same conditions, but were unable to decide what it was that determined the varying amount of energy loss. It was Rubner's great service to point out that the heat production and dissipation, or, in other words, the amount of energy lost, are, under similar circumstances, proportional to the surface area of the body. This law enjoys the widest applicability. The lion and the mouse, the infant, the grown man and the giant give off the same amount of heat per square meter of body surface, provided the conditions are the same. The importance of the skin surface is thus apparent.

An accurate method for the determination of the body's surface area is, therefore, necessary. The formula usually employed is

$$\sqrt[3]{\text{Wt. in gm.}^2}$$

multiplied by a constant, 12.3 or 11.9. For the average well-nourished child or adult, this formula gives excellent results. It is not, I believe, from the results of some of our experiments, accurate for poorly nourished or emaciated beings, and a formula which will give information as to the surface area of these is desirable and capable of being constructed.

We are further indebted to Rubner for determining by a series of thorough and painstaking experiments the utilization of the various food-stuffs and the amount of energy that each is capable of furnishing to the body under normal conditions of digestion, assimilation and excretion. Fat furnishes to the body 9.3 calories of energy per gram ingested, sugar 4.1 and protein 4.1, without reference to the products of incomplete combustion that are eliminated in the urine and feces. The saving of labor as a result of these determinations has been immeasurable, and it is because of these determinations that we may disregard the elimination of the products of incomplete combustion in the urine and feces.

In order to determine the food requirements of an infant, we begin with the assumption that the energy required to keep him in a state of equilibrium is equal to his output. If then, we measure accurately his output, we know definitely the amount of energy required to keep him in equilibrium. To this must be added the amount of energy necessary for his growth. But in order to measure the output, the conditions must be always the same and with the child the conditions can be the same only during sleep. Nothing alters the metabolism so much as mechanical work, and when awake the infant is always performing this, and the amount that each one performs is by no means the same and cannot well

be estimated, though in the individual case it may be experimentally measured.

Rubner and Heubner dispose of the necessity for keeping the conditions always the same by saying that an infant cannot perform a very measurable amount of work, and that whether he is awake or asleep will not greatly alter the results. Their determinations were always made over prolonged periods, twenty hours out of the twenty-four, with the child sometimes awake, active and crying, and sometimes asleep. Schlossmann's results were obtained in much the same way.

During the last year in Dr. Lusk's laboratory, we made experiments with different children with a calorimeter of the Atwater-Rosa-Benedict type, especially constructed for use with small children and animals, which allows a determination of the heat produced, as well as of the oxygen consumed and the CO_2 excreted, with an error of less than 1 per cent. We could show, first, that it is possible to use for comparison only sleeping hours, and that the increase in metabolism in the waking hours is very great over that in the sleeping. For instance, one boy, J. E. N., who produced during sleep 961 calories per square meter of body surface, calculated for twenty-four hours, produced 1,065 calories, similarly calculated, when awake, and 1,130 calories when crying; and another, W. McG., 1,092 calories when asleep, 1,264 when awake, and 1,514 when vigorously crying.¹ Schlossmann has also shown by determinations of the respiratory exchange on the same infant when asleep and when crying, that the metabolism could be nearly doubled, and that an infant weighing only 5 kilograms, when vigorously crying, expended one-fifth as much energy as a full-grown man at hard labor.

It is obvious, then, that children can be investigated satisfactorily only during sleep. This is unfortunate. It makes the one weak link in the whole chain. We can measure exactly how much energy is given off, and consequently how much is required, during the absolutely quiet hours, but the extra amount necessary for muscular exertion remains undetermined.

We made many experiments on a healthy well-nourished child 3 months of age, weighing 4.75 kilos, or a little over 10 pounds. He was fed every four hours during the twenty-four, so as to keep his metabolism as uniform as possible. He was put in the calorimeter shortly after a feeding, and his metabolism determined during a period of three hours, but only sleeping hours were used for the averages. It was found that he produced heat which, calculated in the ordinary way per square meter

1. The difference in the calculated metabolism of these two children when sleeping I believe to be due to the fact that the formula employed for calculating the surface area does not give correct results with poorly nourished children. The second child though lighter than the first was 3.5 cm. longer. Too small a calculated surface area gives too high a metabolism per square meter of surface.

of body surface for twenty-four hours, was equal to 952 calories.² I think it would be safe to say that the requirements for an infant completely quiet would be not very far from this, and that from 940 to 975 calories per square meter a day would allow sufficient latitude.

There are no figures with which these may be compared, as the heat produced by children has never before been directly measured; nor have the sleeping usually been separated from the waking hours, as it had not seemed sufficiently important to do so. Rubner's and Heubner's determinations were made, as I have said, over twenty hours in the twenty-four, the children being awake part of the time. It was impossible to continue the experiments throughout the whole twenty-four hours on account of the feeding, and as the most active periods were those shortly before and after feeding and during the bath, much of the effect of the activity was lost. It cannot, therefore, be considered that their twenty hours represent accurately an average of the twenty-four.

Their determinations on different children were 1,054, 973, 1,106 and 1,180 calories per square meter per twenty-four hours.³ The increase over the figures which we obtained is undoubtedly to be accounted for by the mechanical work that their children performed while awake. The highest figures that they ever obtained, 1,180, were with a very active child who cried much of the time.

If we consider that 940 to 975 calories per square meter of body surface in twenty-four hours is the requisite in sleep, we can only estimate the extra amount required by muscular exertion, and this estimation is extremely difficult, and any errors likely to be enormous. One child differs so much from another in all of his habits; the first may sleep twenty hours out of the twenty-four and be peaceful, quiet and lethargic, seldom crying, and lying contentedly still; the second may sleep only fourteen or fifteen hours, and when awake may be constantly in motion, crying, struggling, turning and twisting, and in all of these extra hours he demands more energy which, as may be seen from the figures that I have quoted, may exceed the energy-demand in the sleeping hours by 40 per cent. or more.

I have reiterated this in order to emphasize just where the difficulty lies. We know the resting requirements, and we know sufficiently accurately the requirements of growth. Cammerer, by the statistical method, which determines the total food intake and urinary and fecal output, showed that one breast-fed infant retained 15 per cent. of the energy-content of his food for growth, and another, 9 per cent. Rubner and Heubner determined that an artificially-fed child retained 12 per cent. for growth. There is apparently a fixed and definite tendency toward

2. I have used 12.3 as the factor in determining the surface area.

3. Rubner and Heubner used 11.9 as the factor in determining the surface area. I have recalculated their figures, using 12.3.

uniform growth, and a definite proportion of food is retained for this purpose. Growth is the natural tendency of the child, and energy sufficient for this must be supplied in order to keep him in a normal condition. It appears that 10 to 15 per cent. in excess of the energy required for equilibrium maintenance makes ample provision for growth.

The requirements for growth are thus seen to be relatively small and by no means explain the great difference in the nutritional demands between the infant and the adult, although before the days of exact measurements this was supposed to be the only reason why the young infant required 100 calories, and the adult 35, per kilogram of body weight. Rubner gave the true explanation, that the difference was due to the relatively greater surface area. The smaller the body, the greater the surface area in comparison with another body of similar composition. As the smaller body increases in size, its surface area becomes relatively less and less, and it is for this reason that the requirements of normal children shrink from approximately 100 calories per kilo in the first few weeks of life, to about 70 per kilo at the end of the first year, and not because the rapidity of growth has undergone any great diminution.

There are known, then, the resting requirements of the infant and the extra quantity necessary for growth, but that amount over and above the other that is necessary to compensate for the activities of the waking hours, is as yet to be obtained only by estimation.

I have refrained from approaching my topic from the side of practical application because, at the present time, it does not seem that we are in a position to utilize the results of the determinations that I have spoken of in an entirely satisfactory way. There are still some additional data that must be supplied, but that it will be possible to do this at some future time I feel reasonably sure.

But the requirements of an infant's nutrition refer to quality as well as quantity. Water must be furnished to the infant in large amount compared with the adult, on account of the infant's great cellular activity. His smaller mass of cells is called on to do almost three times the work that those of the adult have to perform, and they do this to the best advantage only when water is freely provided them.

The salts of potash, sodium, magnesium and calcium are all vitally necessary for the life processes. They are all present in the proper proportion in woman's milk, and are sufficiently represented in any dilution of cow's milk that would be used for any considerable length of time. In the majority of instances, they are in excess in the dilutions given to children, but this excess is not a factor of importance with the healthy child, which is the one that is under consideration. The salts of iron are, however, deficient both in human and, especially, in cow's milk. The large supply of iron present in the liver and other organs of the newly-born, may gradually be drawn on, and evidently is intended to be drawn

on, during the first year, but this deficiency of iron is one important reason why an exclusively milk diet should not be persisted in too long.

The fats and the sugars are the great providers of energy, and together they furnish approximately 90 per cent. of the body's requirements. To a large extent they may be used interchangeably, and an excess of one may for a time compensate for the deficiency of the other, though not indefinitely. Whatever disturbances these produce, are chiefly recognized by gastro-intestinal symptoms such as vomiting, diarrhea, or soapy stools, and so forth. A deleterious effect of either of these on metabolism, so far as the exchange of energy is concerned, has not been demonstrated.

With the protein it is different. This must be furnished in a digestible and assimilable form to repair the loss by wear and tear and to provide for growth, but beyond a certain point there is a marked disadvantage in giving protein. This is not because the casein of milk is difficult of digestion, but because of the effect on metabolism known as the specific dynamic action of protein. By this action, the total heat production of the person ingesting the protein is raised, often to a marked degree. This increased heat must be disposed of. It may be available for warming the body in cold weather, but is an added source of discomfort and possible danger in hot weather, when it is difficult to get rid of sufficient heat by radiation; and it may cause a dangerous elevation of the infant's temperature when the heat-regulating mechanism is not fully developed. In addition, the extra ingestion of protein throws additional work on the organs of digestion, and the processes of intermediary metabolism.

Two experiments that I have made indicate this very well. One child, who produced an average of 952 calories per square meter in twenty-four hours, was given, in addition to his regular diet, 15 gm. of nutrose during the twenty-four hours. Nutrose contains nearly 90 per cent. of protein. As a result of this extra protein his heat production rose to an average of 1,051 calories per square meter, or a little over 10 per cent. The metabolism of another child rose from 1,097 to 1,383, or an increase of 26 per cent., with the addition of 30 gm. of nutrose. This represents an undue, unnecessary and, at times, undoubtedly harmful tax on the organism.

It is probable that slightly less protein is required for maintenance and growth in breast-feeding than in cow's milk feeding, owing to the better utilization that can be made of the homologous protein, but the excess required with cow's milk feeding is undoubtedly slight. When feeding a normal child, protein should furnish not less than 8 per cent. and not much more than 10 per cent. of the total energy in the food. When it furnishes 15 per cent., the specific dynamic action becomes noticeable, and when it furnishes 20 per cent., the effect is very marked.

It will be seen, therefore, that in addition to the quantity of the food provided, a proper disposition of the energy among the various constituents is always seriously to be kept in mind.