Nutrient-to-Calorie Ratios in Applied Nutrition

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ABSTRACT

This paper discusses the desirability of expressing the nutrient requirements of man and animals relative to their associated energy intake, and proposes a format for expressing a dietary standard for humans. Caloric needs are known to vary with size, activity, and productive performance. There is agreement that most of the nutrients quantitatively considered in diet or ration formulation should remain in balance with each other and with energy, for optimal food efficiency. Many nutritionists believe that it is not possible to state the requirements for individual nutrients without also specifying the amounts of others also to be ingested. In the case of nutrients that must be stored in the body, as during growth, the ratio to energy intake changes progressively to the final adult equilibrium status. In the case of the human, one adult, and 3 juvenile "diet" categories appear to be adequate, within each of which the interbalances between nutrients and that between nutrients and energy are constant. Within these 4 categories, adequate daily nutrition can be accomplished by adjustments in the intake of the diet as a whole.

One of the far-reaching concepts in dietetics and animal rationing is the importance of balance between the nutrients of the diet — the realization that relative excesses are no less undesirable than relative deficiencies. We have only begun to unravel the picture of nutrient interrelationships, but it is abundantly clear that the efficiency of food utilization by the animal body may be markedly affected by alterations in the inter-nutrient balance, or between the nutrient and energy pattern, or both. There may be some doubt whether we yet can define the ideal interrelations, but periodically since 1810 tabulations have been made of the quantities of energy and of nutrients that evidence indicated were needed daily by farm animals according to species, weight, age, sex and production performance.

One pertinent study was that by Gulbert and Loosli (1) in which they computed for farm animals and poultry from the appropriate feeding standards (NAS-NRC series) the recommended daily feed intakes, and total digestible nutrients (TDN); and per unit TDN, the digestible crude protein, calcium, phosphorus, carotene, vitamin A, vitamin D, thiamine, riboflavin, niacin and pantothenic acid for individuals at attained weights of from 10 to 100% of expected adult size. Although their study was mostly concerned with immature growing animals, and was hampered by excessive variability partly from the fact that the NAS-NRC feeding standard values at that time contained margins of safety of unknown magnitude over the true requirements, they prepared a table of generalized recommended allowances of protein, Ca, P, thiamine and riboflavin in ratio to TDN intake for farm livestock and poultry. They state, "The feasibility of expressing (in feeding or dietary standards — E.W.C.) the relationship of the various nutrients with metabolizable energy rather than with total digestible nutrients should be explored." They also comment, "In the preoccupation of seeking new nutritional factors, it would appear desirable to pause when they are found to determine their fundamental relations to other nutrients, to body weight, or to caloric intakes, and the quantitative requirements in a systematic procedure."

Because of incomplete knowledge, the authors of the early tabulations often claimed as requirements, nutrient values later shown to be excessive; and it is significant that, other than inclusion of additional nutrients, the chief changes in the chronologically successive "standards," even though by different authors, have been downward revisions of the amounts of nutrients believed to be required relative to energy intake. The criteria for such changes have been: increased efficiency of the ration in producing growth, fattening, milk or egg production, or de-

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increased mortality, or both, or evidence of dietary-induced morbidity — all of which have a direct bearing on the economics of the livestock enterprise.

In standards applicable to captive animals, the relationship that has been least modified with the passing of time has been that between energy and protein, although it was the first to appear. Indeed, it was the proportion of protein to "carbohydrate equivalent" that was the basis of Henry's (2) "nutritive ratio," a term coined by him in 1904. The term, "balanced ration," originally referred quantitatively only to its protein-to-energy ratio, although it was defined by Henry as: "... a combination of farm foods containing various nutrients in such proportion and amount as will nurture the animal for 24 hours with the least waste of nutrients."

Distortion of the protein-to-calorie ratio was more promptly reflected in animal performance than most other formula modifications, and quite naturally led to ascribing a greater importance to protein levels than to that of other nutrients. Because high protein feeds were more costly than those used primarily for energy, minimal protein levels compatible with maximal ration efficiency were understandably considered optimal levels.

Until the early 1950's, the practical expression of protein-energy balance in animal and poultry diets was the percentage of protein per unit weight of ration dry matter. The energy concentration of such rations for a given species deviated only between relatively narrow limits. Adjustments of energy intake according to desired rates of growth, fattening or production, or to meet the maintenance needs of animals of varying sizes, were made by regulating ration allowances. Since other nutrients than protein were contained in the ration mixture, they, too, were automatically consumed in fixed, although often unknown, ratios to calories, and to each other.

Increasing energy intake to obtain greater performance by allowing greater daily consumption of the diet mixture obviously has strict limitations, and about 1954, as an alternate method, poultry nutritionists began to increase the energy concentration of the diet by direct additions of edible fat. In the 1960 revision of the NRC publication on the requirements of poultry, the NRC Poultry Feeding Standard Committee (3) states, "It has been customary for research workers in poultry nutrition to express nutrient requirements in terms of nutrient per unit weight of ration ... This convenient method is inaccurate ... (because) ... protein requirement can be defined accurately only in relation to energy concentration . . . ."

The need for maintaining specified protein-to-calorie ratios in diets is not restricted to poultry rations. Stare (4), in summarizing the findings of a symposium on protein nutrition in 1958, comments: "The last point, and probably the most important, is the concept of the balanced diet or balanced nutrition . . . ." "... the type of nutrition that supplies a sufficiency, but not an excess, of calories coming from both carbohydrates and fat . . . in adequate ratio with . . . vitamins, minerals and amino acids." During the same symposium, Johnston (5) stated: "The ratio of calories to protein is one of the most important problems . . ." and we cannot speak about the protein needs without taking calories into consideration. It is better not to speak of the amount of protein per kilogram daily, but to express it as the percentage of caloric intake." Hegsted (6), in his 1958 paper, "Protein Requirements in Man," states: "... emphasize the rather high correlations between protein and caloric intakes. These are expected, but often ignored."

There is sound biological basis for considering caloric intake as the fundamental basis for the requirement of most of the known essential nutrients. It is concisely stated by Kleiber (7) in his review of dietary deficiencies and energy metabolism. He writes, "Since any dietary deficiency, in contrast to lack of food, means an imbalance of the ration, one may derive from Mitchell's hypothesis, a bioenergetic criterion for a dietary deficiency leading to the following definition: A diet is deficient in any nutrient whose addition decreases the calorigenic effect of the ration. One may expand this definition, and state that a ration is deficient (and hence unbalanced) in any food constituent whose addition increases the total efficiency of energy
utilization.” This merely says that, the specific dynamic action of food represents waste energy, which can be minimized by proper balance of the energy and nutrient content of the diet.

In Kleiber’s review (7), he finds evidence that changes in proportions to energy intake, of 1) potassium, magnesium, calcium, phosphorus, iron, iodine; 2) of ascorbic acid, thiamine, riboflavin, niacin (B vitamins as a group), probably of vitamins A, D, and E; and 3) of protein, affect metabolic rate. He partially summarizes these observations in his recent book (8) as follows: “Not only the requirements of food energy, but also that of protein and of most vitamins may be expressed per unit of the three-quarter power of body weight (W^3/4), because these dietary requirements are directly related to energy metabolism.” Brody (9) states: “As regards the maintenance needs for vitamins and trace elements, those that are involved in the general oxidation-reduction processes of intermediary metabolism, . . . undoubtedly vary directly with energy metabolism — that is, with the food energy consumption.”

Adult protein-calorie ratios for maintenance living

Obviously, then, nutrient requirements may well be expressed relative to calorie needs, and it may be of interest at this point to present the published maintenance digestible energy requirements of adults of different species with their digestible protein needs — the relationship which has been more widely and accurately established in biological research and in practical feeding than any other.

The conformity of the protein-to-calorie ratio for mammalian species, differing as widely in size as rats and cows, strongly supports the premise that digestible protein is required for adult animals at maintenance living in about the same ratio to digestible energy needs, regardless of species or size.

The common belief that sex, per se, affects the adult maintenance dietary requirement is probably unwarranted. It has been shown (10, 11), that for energy requirements, sex difference is primarily a size difference. Nor is any distinction made between sexes, per se, in ration formulation for the feeding of idle adult farm or laboratory animals.

**Protein-to-calorie requirements of adults — super-maintenance living**

Within the adult group within each species, there are subgroups that, because of their differing functions or activities, might conceivably require rations differing from those of simple maintenance living.

**Pregnancy.** During pregnancy there is a gradual increase in basal metabolism to a maximum, at term, of 120% of the nonpregnant state. There is also an accumulation of products of conception. Most of these changes are insignificant, nutritionally, until the last third of pregnancy. During the last trimester the voluntary activity of the mother is usually progressively reduced so that there may be only a relatively small, if any, increase in caloric needs for “work.” In any case the maximal extra daily metabolizable energy intake needed by pregnant women probably does not exceed 520 kcal (11, p. 388).

As to protein, Terroine (12) estimates that in human pregnancy not more than one gram per day of nitrogen is required for the formation of the fetus, its adnexa, and the expected increase in body protein

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**TABLE 1**

<table>
<thead>
<tr>
<th>Grams digestible protein required daily per 1000 digestible kcal of dietary energy for adult maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Man</strong></td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Typical adult wt, kg</td>
</tr>
<tr>
<td>Digestible calories, kcal</td>
</tr>
<tr>
<td>Digestible protein, g</td>
</tr>
<tr>
<td>Protein/1000 kcal</td>
</tr>
</tbody>
</table>

1 Computed from current Canadian dietary standard (23).
2 Computed from NRC feeding standard (24).
3 Computed from Brody-Kleiber equation (14, p. 138).
stores of the mother. If this is all demanded during the last third of pregnancy it is easily computed as (3 g × 6.25) 18.75 g of protein/day for this period. This would mean increasing the protein-to-calorie ratio in the diet during that period to 22 from 19 g/1000 kcal. However, there may be some doubt that this extra protein is normally advisable. It has been shown by Harris1 that with range cattle extra fetal growth may be stimulated by supplementary dietary protein to the pregnant female, often resulting in difficult parturition sometimes fatal to the dam. Furthermore, omission of such supplement in no way prevents the young from reaching "normal" weight at weaning.

Modern feeding standards do not indicate any change in the nutrient balance of the ration during pregnancy for dairy cattle, beef cattle, swine, dogs or rats. In any case there is no evidence that, with normal diets, the possible slight drain on the body protein "reserves" of the mother to meet the full needs of the fetus are of measurable consequence. Platt (13) summed up the case for the human very concisely in the statement that, "An increase in the diet towards the end of pregnancy should be regarded as preparation for successful lactation. I think that is more to the point, perhaps, than finishing off the fetus." There is practical observation from all classes of farm mammals to support this view. Platt's remark is of some interest today when inhibition of lactation in some species seems to be of more concern than preparation for an abundant milk flow.

It is of interest also that, wherever any upward adjustment in allowance is made in the feeding of pregnant farm animals, it is made by increasing the quantity of the normal ration as a unit.

Lactation. The belief is commonly held that for lactation, dietary protein needs are increased to a greater extent than those for energy. A few simple calculations may clarify some of the facts as they are now accepted.

The efficiency of the energy of a normal diet for the production of milk energy is about 61% in the case of the cow, and this value has been applied to the human. On this basis, to produce 850 ml of human milk carrying 0.75 kcal/ml require (850 × 0.75) ÷ 0.61 = 1045 metabolizable dietary kcal.

If we assume an efficiency of dietary protein for human milk protein production of 75% (as it is with the cow), we can compute that to produce 100 ml of milk carrying 1 g of protein will require (1 × 100/0.75) = 1.33 g, and for 850 ml (1.33 × 8.50) = 11.3 g of dietary protein. Thus, for a daily (average) lactation of 850 ml the diet must supply 1045 kcal and 11.3 g of protein; or 10.8 g protein/1000 kcal of metabolizable energy. Some estimates place the dietary protein efficiency for human milk protein at 50%, in which case 16.3 g dietary protein/1000 kcal would be needed for human lactation. This is still less than the 19 g provided in the normal non-lactating diet. It is therefore probable that the normal maintenance diet supplying 19 g protein/1000 kcal needs no protein supplementation to make it adequate for lactation.

The milks of different mammalian species, however, differ in nutrient composition and hence require differing proportions of nutrients to energy for their production. For example, cow's milk carries 3.5 times more protein per liter than human milk, but only some 4% more energy. Consequently the ration digestible protein needed per 1000 digestible kcal (using the same ration efficiency as for the human) is about 3.6 times that for human milk (i.e., 39.0 g vs. 10.8 g). Table 2 shows rounded approximate values for 5 species.

There should be no change in the energy-to-protein ratio of the bovine diet for different levels of production (14, p. 325), the only adjustment being in the quantity of the ration fed. In the case of rats, dogs, sheep, and swine, where lactation is not measured directly, the adjustment of daily ration intake is either left to the nursing mother through ad libitum feeding, or is regulated by the feeder in accordance with the number of young in the nursing litter.

Incidentally, in modern practice the time of weaning from milk of calves and of baby pigs is often reduced from 30 to 5 and 60 to 15 days, respectively. Neverthe-

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1 Harris, L. E., Professor, Department of Animal Science, Utah State University, Logan, Utah. Personal communication.
less, with respect to early weaning from suckling, livestock practice has lagged behind that in the human family. Results of early weaning in general have been more rapid growth of the young than during comparable periods of nursing, and have made it clear that the nutritive properties of milk as an entire food for young mammals can be duplicated by other food combinations. The faster growth of early weaned young is, however, more often a reflection of fully adequate amounts of the diet, than of a more suitable balance of nutrients.

Quantitatively, the “normal” diet of the nursing mother should be increased daily to provide approximately 125 kcal extra for each 100 ml of milk produced. This amount of metabolizable energy (i.e., $125 \times \text{milliliters of milk produced per day}$) should be added to her caloric requirements for maintenance plus that appropriate to her physical activity.

**Work (or other muscular activity).** One further dietary category of adults—that of the physically active individual—remains to be dealt with, and is of importance with only 3 species: dogs, horses, and man. This category presents a unique situation, in that practice and classical theory are at sharp variance. Based on nitrogen balance studies, most of which were conducted on horses or men early in the century, nutritionists generally have been satisfied that physical exercise, per se, while requiring energy, does not demand any increase in protein intake over the maintenance level.

In 1963, however, Consolazio et al. (15) published the results of a 1960–61 N balance study, the data of which are of direct significance in this problem. In the report of these workers they comment pointedly that, “In general nitrogen balance losses have included only the urine and fecal excretions, although nitrogen losses also are observed in sweat and can possibly be found in expired air.” They call attention to the fact that recent publications on human allowances have not considered the effect of these losses on nitrogen requirements. With respect to their observations in general, they state: “... there is an increase in sweat nitrogen with ... an increase of physical activity ...” even under conditions of fairly high protein intakes ... the nitrogen balances were quite negative when the sweat losses were included.” And again, “... the urinary and fecal nitrogen losses were remarkably constant signifying that the increased sweat nitrogen excretions are not compensated by decreases in the urine and feces.”

Some of the data from this balance study can be used in computations pertinent to the subject under consideration in this paper. They are summarized in table 3.

### TABLE 3

**Some computations with respect to protein-kilocalorie requirements for work**

<table>
<thead>
<tr>
<th>Description</th>
<th>Calculation</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy expenditure at imposed work</td>
<td>$50 \text{ min} \times 1.14 \text{ liters } O_2 \times 4.825 \text{ kcal/liter}$</td>
<td>$338$</td>
</tr>
<tr>
<td></td>
<td>$50 \text{ min} \times 0.75 \text{ liters } O_2 \times 4.825 \text{ kcal/liter}$</td>
<td>$171$</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td>$509$</td>
</tr>
<tr>
<td>Equivalant digestible dietary kilocalories</td>
<td></td>
<td>$549$</td>
</tr>
<tr>
<td>Subsequent “daily” dermal protein loss</td>
<td>$1273 \text{ mg N} \times 6.25 = 1000$</td>
<td>$7.93 \text{ g}$</td>
</tr>
<tr>
<td></td>
<td><strong>Equivalent replacement digestible dietary protein</strong></td>
<td>$10.5 \text{ g}$</td>
</tr>
<tr>
<td>Digestible protein required/1000 digestible kcal</td>
<td>$10.5 \times 1000$</td>
<td>$19.1 \text{ g}$</td>
</tr>
</tbody>
</table>

1 Based on reported average excretion of nitrogen in sweat per 7.5-hour exposure period, comprised of two 50-minute periods of exercise on an ergometer and the remaining time of 5.5 hours at sedentary activity, in an environmental temperature of $21^\circ C$ in one series and $47^\circ C$ in a second.

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**TABLE 2**

**Grams digestible protein required per 1000 digestible dietary kcal to meet the specific needs of lactation**

<table>
<thead>
<tr>
<th>Species</th>
<th>kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>11.0</td>
</tr>
<tr>
<td>Cow</td>
<td>29.0</td>
</tr>
<tr>
<td>Sheep</td>
<td>35.0</td>
</tr>
<tr>
<td>Sow</td>
<td>35.0</td>
</tr>
<tr>
<td>Dog</td>
<td>55.0</td>
</tr>
</tbody>
</table>
These computations appear to support the premise that for nutritional equilibrium, physical activity requires protein as well as energy, and its amount per 1000 kcal of diet is about that of the normal maintenance ration. Hence the need can be met by an appropriate increase in the normal diet as a whole.

The use of nitrogen balance as the criterion of dietary protein requirement is complicated by the presence in the body of tissue (or cell) reserve protein which can be mobilized to "make good" current inadequate intake. Thus N equilibrium can be established at any level of protein intake above maintenance. In order, therefore, to demonstrate a protein requirement for exercise by N balance studies one must show either a greater output than intake of nitrogen, or a decrease in labile (reserve) tissue or cell nitrogen, or both, as a consequence of an imposed work load. Our own studies* lead us to believe that, depending on intake level, different tissues may, simultaneously, respond differently to exercise, in that blood serum albumin may decline while the gastrocnemius muscle N increases, and the skin remain unchanged in nitrogen content (as measured in these tissues, respectively, by albumin-to-globulin ratio; total N concentration; and RNA/DNA-to-total N/DNA ratios).

Direct estimation of the protein status of the body still awaits dependable methods, but ultimately, working adult animals consuming diets providing adequate energy for the work load involved, but restricted in protein intake to maintenance needs must show either negative nitrogen balance, or a loss in weight from depletion of body nitrogen reserves, or both, if nitrogen is in fact required for muscular exercise.

In practice it is not practical to increase the energy intake of horses or dogs at work, without also increasing the intake of protein. To provide horses with extra energy for work, addition of any suitable grain to the hay or hay-plus-grain maintenance diet results in an increase in the protein-to-energy ratio. For most dogs the working diet is simply more raw meat, or fish, or both, with the extra protein furnishing the needed additional energy.

With man, however, whose diet under usual living is put together in bits and pieces, with neither the parts nor their proportions ever the same either between comparable persons or for the same person at different meals or on different days, there is the possibility of incorporating essentially "empty calories" to meet the increased energy for work. If the maintenance diet is balanced to supply only the presumed maintenance protein requirement, then the addition of "empty calories" to meet the increased energy demands for work, results in a ration with a reduced energy-to-protein ratio, or as it is expressed by some, a wider nutritive ratio. With respect to such diets Mitchell (16) writes: "In practical nutrition, and in the absence of economic stringency or the unavailability of protein-rich foods, minimal protein nutrition is not in vogue; diets with the wide nutritive ratios associated with this type of nutrition are not palatable and are not selected from choice. Super-maintenance protein feeding during growth and muscular activity will provide the dispensable protein stores so advantageous when physiological adversity strikes. During muscular activity the increased caloric needs are commonly met by an increased consumption of the usual diet, not by the addition to this diet of non-nitrogenous items."

Most human foods when added singly to a balanced maintenance diet to supply "work" calories, result in altered ration balance through excesses of some nutrients, or shortages of others (including amino acids, minerals, and vitamins), or of both (table 4).

Deliberate diet alteration to satisfy the worker or athlete is usually accomplished by increased allowances of meat, fish, cheese, and to a lesser extent, of bread and potatoes. The former supply from 50 to 150, and the latter 20 to 30 g of protein/1000 digestible kcal, and their addition to the diet actually adds more protein relative to the energy than is called for in the maintenance diet. Most cakes and pastry furnish 10 g or more of protein/1000 kcal, and when combined with such foods as noted above, result in a final mixture that

* Unpublished.
Nutrient-to-calorie ratios in applied nutrition

Table 4

Nutrients per 1000 digestible kcal of the edible portion of the foods indicated (approximate values)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>&quot;Sedentary&quot; diet</th>
<th>Sugar</th>
<th>Fats</th>
<th>Potatoes</th>
<th>Bread</th>
<th>Milk</th>
<th>Beef</th>
<th>Eggs</th>
<th>Fish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digestible protein, g</td>
<td>19.0</td>
<td>0</td>
<td>1</td>
<td>20.0</td>
<td>31.0</td>
<td>51.0</td>
<td>60.0</td>
<td>78.0</td>
<td>160.0</td>
</tr>
<tr>
<td>Thiamine, mg</td>
<td>0.3</td>
<td>0</td>
<td>0</td>
<td>0.8</td>
<td>0.3</td>
<td>0.6</td>
<td>0.3</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Riboflavin, mg</td>
<td>0.7</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>0.3</td>
<td>3.0</td>
<td>0.5</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Iron, mg</td>
<td>3.0</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>3.0</td>
<td>1.0</td>
<td>8.0</td>
<td>2.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Caries at least the “normal” 19 g protein/1000 digestible kcal.

It appears, then, that recent studies support the view that physical exercise does in fact impose not only an energy requirement, but also a corresponding dietary protein requirement, and that in amount the latter is in the same ratio to the former as it is in the properly balanced maintenance diet. This view is consistent with a statement in the report to the FAO Committee on Protein Requirements (17) that, “In increase in muscle mass associated with athletic training and with seasonal increase in muscular activity creates a need for protein in addition to the average minimum requirement.” (and) “... in such circumstances the reference requirement for the group undertaking such heavy work should be substantially raised.”

The question of whether muscular activity per se requires protein is largely academic in areas where protein-rich foods are economical and abundant, in the sense that the practical feeding of “working” individuals almost always results in the addition of adequate protein incidental to providing the needed extra calories. This is no way justifies ignoring the evidence or specifically indicating in feeding or dietary standards that physical activity does not require protein expenditure over that of sedentary living. Dietary standards (as distinct from recommended allowance tables) are (or should be) scientific documents intended to give minimal nutrient requirements compatible with health and performance of the individual specified. As such they serve an important function in guiding agencies (usually governmental) which must provide food or regulate its distribution under conditions of emergency or disaster where restriction or rationing must be imposed.

Growing animals

In the case of growing individuals, where appreciable positive N, Ca, and P balances are necessary, the acceptable diet must carry an increased concentration of these nutrients. Since juveniles are also more active than sedentary-living adults, the growing-period energy allowances are also larger per unit of body weight, than for adults. Many nutrients, however, should remain in fixed ratios to energy, since they are primarily needed to metabolize energy.

The actual dietary demands for protein relative to energy by the growing boy or girl are not as great as is popularly supposed. Terroine (18) calls attention to the error in the common belief that “... the whole of the physiology of the child is dominated by the need for protein synthesis, and that they are, as it were, factories for the intensive production of such proteins.” His data show that the net growth requirement for protein “rarely exceeds 2 grams per day.” Hegsted’s (19) calculations agree with Terroine’s data, and he also emphasizes “the relatively small contribution that growth makes to the protein need of the child after the first few months of life.”

Using the assumption that the true maintenance protein requirement is 12.5 g/1000 basal kcal, and that gains in weight are 18% protein, Hegsted (19) observed that the total daily net protein requirement of children was essentially constant at about 14 g/1000 basal kcal. To check the latter, Mitchell (16) used data from other sources but similar assumptions, and predicted daily gains. He found an average of 13.8 g protein/day per 1000 basal kcal, but a slightly greater tendency for higher protein in the first 2 years of age. He concludes that, “... regardless of sex, rate of growth, and age, between 1 and 2
years and early maturity, the total net protein requirement for maintenance plus growth varies with the basal metabolism of energy so that it amounts to 13–15 grams per 1000 basal calories per day."

His tabulation shows values for 16.3 and 14.6 g protein for ages 1 and 2 years; and 13.9 to 12.9 for ages 3 to 19 years, respectively.

Insofar as digestible protein intake in relation to digestible energy need is concerned, it is, with all species, a continuously declining variable following the true growth rate of the juvenile in question. The general pattern can be seen by plotting the somewhat comparable data for digestible protein required per 1000 digestible kcal for children and for market pigs against successive weights, the weights expressed for each species as the percentage of the adult metabolic size attained. The limited data available from the latest feeding standards thus plotted, and the regressions fitted by inspection, are shown in figure 1. This chart reflects clearly the uniquely long juvenile period in the human species.

From the practical standpoint it is neither feasible, nor necessary, to adjust daily the nutrient-to-calorie ratios for growing individuals. In pig feeding the growing period is divided into 3 “ration” periods: 4.5 to 18 kg; 18 to 55 kg; 55 to 91 kg, during which the protein per 1000 kcal is successively changed from 37 g to 30 g to 25 g. The 4 “steps” of change in ration balance are shown on the graph; and suggested comparable steps for the human are marked in accordance with the position of the appropriate plotting points. These latter suggest 3 “growing” rations, with changes of protein concentration per 1000 digestible kcal from: 28 g to 23 g to 21 g to the adult 19 g, to be introduced when 22, 35, and 72%, respectively, of adult metabolic weight has been attained.

**Quality of protein**

In the above discussions of protein-energy balance, no mention has been made of the effect of quality of protein on the daily amounts required for adequacy in any given case. This factor must be considered, however, because as the biological value of the protein declines, increasing quantities must be ingested to provide retention of the amounts of the essential amino acids needed. It is convenient to consider the dietary protein complex of North Americans as excellent, good, or average, corresponding to biological values (BV) of 100% (animal + marine), 75% (1 animal + 1 marine + 1 plant), and
50% (1 animal + 1 marine + 2 plant). The equivalent intakes of these 3 categories are not exactly known; but Leitch and Duckworth (20) reported daily intakes of 52 g of protein of average quality gave equal chances of positive or negative N balance with adults. The Princeton Conference (21) concluded that 32.5 g was adequate where quality was good, and the FAO Committee on Protein Requirements (17) reported that 24.5 g of excellent quality protein was adequate to maintain N equilibrium with adults.

To specify, then, the minimal protein intake required daily or per 1000 kcal, its BV must be known or estimated. The 3 minimums (24.5, 32.5, 52.0) represent increases in necessary intakes of the order of 100: 132: 210%, to correspond to declining BV of 100: 75: 50%. Since a 70-kg adult human at light work (550 kcal for work) requires about 2800 metabolizable kcal daily, minimal protein requirements per 1000 kcal could be computed for 3 qualities as: BV 100% = 8.8 g; BV 75% = 11.6 g; BV 50% = 18.5 g.

Inter-nutrient balances

The problems of balance between amino acids, between mineral elements, and between vitamins, to say nothing of intergroup balances and their ratios to energy, are under active experimental study for many species. To date no data are available which indicate their optimal proportions in the human diet, except for the FAO (17) pattern of amino acids. It becomes necessary, therefore, for the present to assume that the minimal amounts of nutrients needed daily by a specified individual, as the reference man of the NRC Food and Nutrition Board recommended allowances (22), represents a working balance pattern between whatever nutrients we are to include in a human dietary standard.

We must also make assumptions, in almost all cases, regarding the caloric intake of human subjects on whose performance the nutrient requirements have been based, for this has seldom been reported. The subjects have been described as to sex, weight, and activity, but not often quantitatively as to energy intake. From the descriptions offered it is probable that most trials involve subjects who could be classed as 70-kg males at very light “work,” such as young adult medical students. For them we can assume a daily metabolizable energy need of 2250 kcal for maintenance plus about 550 kcal for activity in excess of sedentary living. This estimate of daily intake of 2800 kcal is realistic enough to serve, in this proposal, as a working base for computing the nutrients required by adults per 1000 kcal of metabolizable dietary energy.

Energy, the least common denominator for the dietary standard

Nutrient and energy needs of individuals or groups of individuals for whom the same “balance” in their rations is optimum, are ultimately determined by feeding trials or other experimentation. As an example, assume that from the published results of such tests an investigator assembles evidence that the minimal requirement for healthy 70-kg male adults, at light work (550 kcal) is, on the average: energy, metabolizable, 2800 kcal; protein (good quality), 32.5 g; calcium, 450 mg; thiamine, 0.56 mg. In accordance with present thinking, other adults, heavier or more active, or both, but otherwise comparable, will require more of each of these diet components, but with the same inter-nutrient and nutrient-energy balance. The tabulation of the needs of such groups can be generalized if the nutrients are expressed in amounts per 1000 kcal, as: energy, 1000 kcal; protein, 11.6 g; calcium, 160 mg; thiamine, 0.2 mg.

To arrive at the minimal daily nutrient requirements for a person it is necessary to ascertain his daily caloric needs, and to compute for each nutrient:

\[
\text{Nutrient/1000 kcal} \times \frac{\text{daily kcal required}}{1000}
\]

For purposes of dietary standards, the daily energy needs may be estimated for adult individuals from their weights. For purposes of this discussion we shall use the general equation (11):

- For maintenance, kcal 24 hr = 93(Wb^0.72)
- For “light” work, kcal 24 hr = 93(Wb^0.72)
- For average work, kcal 24 hr = 55(Wb^0.72)

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Since the energy requirements of man and the energy of his foods and diets is universally expressed in terms of metabolizable kilocalories, this category of energy will be used in the remainder of this review.
From these equations it is possible to compute the daily caloric needs of a 70-kg man at average work, or of an 80-kg man at light work, as in table 5.

To obtain the 24-hour dietary requirements for these men, the calories and nutrients per 1000 kcal are multiplied by 3.58 and 3.1 for the 70- and 80-kg adults, respectively.

If, in addition to a statement of minimal requirement, a guide to daily nutrient allowances is also wanted, the requirement values may be increased systematically by an appropriate factor. For example, the standard deviations of voluntary food intake under unrestricted allowances is of the order of 16% of the average for domestic farm animals fed identical rations and differing in live weight by 10% or less. It is known that over extended periods, mature farm animals and adult humans tend to consume their respective diets in amounts that maintain a steady body weight. Until data are available, it might be assumed that the variability in voluntary caloric intake of adult humans of comparable weight might also be of the order of 16% of their average energy requirement. On this basis increasing average nutrient requirements relative to energy by 50% would "insure" adequate allowance of nutrients for 599 out of 600 individuals. The single exception probably should be considered a diet therapy case.

In general no nutritional benefit can be expected, and risk of undesirable results might be incurred by continued intake of some nutrients in excess of 50% over need. However, increases in the total diet without change of total nutrient-energy balance are largely innocuous except where problems of overweight are involved.

To return to our example, the final values for the 70- and 80-kg men are shown in table 6.

The necessity for computing specific caloric needs by formula can be avoided by preparing a regression chart with weights along the axis and using multiple ordinate scales to accommodate categories in addition to sedentary living that contribute to the total caloric need, but must be independently determined. Figure 2 is such a chart for humans. It includes juveniles, and 3 categories of work intensity as well as adult "sedentary" living.

The number of different tabulations of nutrients necessary in a complete dietary or feeding standard will correspond to the number of rations requiring different nutrient balance. For man there appear to be at least four: one for adults, three for

<table>
<thead>
<tr>
<th>TABLE 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Daily caloric requirements of two adult men</strong></td>
</tr>
<tr>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>70-kg Man, average work</td>
</tr>
<tr>
<td>80-kg Man, light work</td>
</tr>
</tbody>
</table>

1 All numbers rounded to practical values.

<table>
<thead>
<tr>
<th>TABLE 6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Example of tabulation of dietary requirements and the maximal recommended allowances</strong></td>
</tr>
<tr>
<td><strong>Energy and nutrients</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Energy, metabolizable kcal</td>
</tr>
<tr>
<td>Protein, g BV * 100%</td>
</tr>
<tr>
<td>BV 75%</td>
</tr>
<tr>
<td>BV 50%</td>
</tr>
<tr>
<td>Calcium, mg</td>
</tr>
<tr>
<td>Thiamine, mg</td>
</tr>
</tbody>
</table>

1 See text, page 362.
* BV indicates biological value.
juveniles, plus one (optional) for adults to show the upper limits nutritionally justified (i.e., above which no nutritional advantage can be expected). In the case of juveniles in each of three feeding categories no change in nutrient concentration in the dietary energy is warranted with the present meager knowledge of requirements.

Table 7 illustrates the tabulation of daily human nutrient requirements and the maximal limits justifiable per 1000 kcal. (The data are examples only and imply no official acceptance as requirements.)

To convert these tabulations to daily nutrient needs requires only the figures for the necessary daily energy intake, as from figure 2. As read from figure 2 the needs of juveniles, and for adults at sedentary living are obtained directly as single values; but for adults at work, a second reading from the appropriate "work scale" is necessary, and the 2 values (sedentary and working) added to obtain the total day's requirement. The change in energy requirements shown between boys and girls is not universally agreed on, but is incorporated here to illustrate the possibility of its inclusion in this method.

As an example, assume a family group of:

- Man 70 kg average work
- Wife 60 kg light work
- Son 30 kg normally active
- Daughter 16 kg normally active

From figure 2 we determine the energy requirements to be:

- Man 2250 + 1330 = 3580 kcal
- Wife 2010 + 500 = 2510 kcal
- Son 2275 kcal
- Daughter 1550 kcal

To obtain the daily dietary nutrient requirements the amount of the several nutrients tabulated in the column of table 7 for adults are multiplied by 3.58 and 2.51 for the man and wife, respectively; and by 2.275 and 1.55 for the son and daughter, respectively.

In summary, it appears to this author that there is valid evidence to justify the conclusion that energy intake directly or indirectly "determines" for most nutrients the intake that is compatible with maximal efficiency of the diet as a whole in the maintenance and productive performance of the animal body.

The method of computing the desirable nutrient makeup of diets illustrated facilitates maintenance of the same "intra-

* See page 362, column 2.
group" balance between nutrients, as well as between energy and the nutrient groups as a whole, in rations required in different amounts daily to meet size or performance differences, or both, of the individuals of the same diet category. Tabulation of the complete "standard" is also greatly simplified and condensed without sacrificing necessary or desirable detail. Expansion to include further nutrients or additional dietary groups, or both, is practicable if and where such may be found desirable as a consequence of new facts on requirements or to meet special circumstances.

Finally, the plan is applicable to all species for which feeding standards are prepared, and the form of tabulation facilitates recognition of similarities in comparative nutrition.

LITERATURE CITED


