Energy and protein requirements

Report of a Joint
FAO/WHO/UNU Expert Consultation

World Health Organization
Technical Report Series
724

World Health Organization, Geneva 1985

ISBN 92 4 120724 8

ISSN 0512-3054

PRINTED IN SWITZERLAND

84/6191 – Schüler S.A. – 10 100

CONTENTS

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1. INTRODUCTION

The Joint FAO/WHO/UNU Expert Consultation on Energy and Protein Requirements[1] took place in Rome from 5 to 17 October 1981. The Consultation was opened by Professor Nurul Islam, Assistant Director-General, Economic and Social Department, FAO. He welcomed the participants on behalf of the three agencies and emphasized the need for a re-examination of the requirements for energy and protein in the light of recent scientific developments.

More than ten years have elapsed since the Joint FAO/WHO *Ad Hoc* Expert Committee on Energy and Protein Requirements (*1*) met in 1971. That meeting was the first of its kind at which the requirements for energy and protein were considered together. In its terms of reference the Committee "was asked to examine the interrelationships between requirements for energy and proteins and to recommend means for the integration of requirement scales for energy and proteins, if that were feasible". This was clearly an important step forward.

In its report (*1*), published in 1973, the 1971 Committee reviewed the principles on which some other groups of experts had based their recommendations on energy (*2, 3*) and on protein (*4*) requirements. It had been stated consistently that estimates of nutrient needs were concerned with groups and not with individuals. The 1971 Committee confirmed that assertion but emphasized two additional points: (*a*) that estimates of requirements are derived from individuals rather than groups, and (*b*) the nutrient requirements of comparable individuals often vary. The Committee further pointed out that requirement estimates can be related to individuals, but only on a probability basis; this concept is developed further in the present report.

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[1] A list of participants is given in Annex 10.

The first two FAO Committees on Calorie Requirements (*2, 3*) established three general concepts:

(*a*) The energy need of a group is represented by the average of the needs of individuals in that group.

(*b*) As far as possible, energy requirements should be determined from estimates of energy expenditure.

(*c*) The energy requirement of a "reference" man or woman constitutes the baseline for the assessment of energy needs of people in general. Adjustments are then made for deviations from those reference requirements for different states and situations such as growth, pregnancy, lactation, aging, climate, etc.

In general, these concepts have stood the test of time.

Ideas on the assessment of protein requirements have progressed in a rather different way. The FAO Committee on Protein Requirements (*4*), which met in 1955, placed particular emphasis on the pattern of human amino acid requirements and the definition of requirements in terms of a reference protein with an "ideal" amino acid composition. Quantitative estimates of protein requirements were based on information available at that time on the needs for essential amino acids. In 1963 a Joint FAO/WHO Expert Group on Protein Requirements (*5*) introduced the new concept that the requirement for protein is determined by the rate of obligatory nitrogen loss from the body (principally in the urine, but also in faeces and through the skin) when the diet contains no protein. Measurement of these losses should provide an estimate of requirement, with correction for protein quality.

The 1971 Committee made advances in two directions. First, it recognized that even with protein of high biological value, the minimum nitrogen intake needed to ensure balance, which has generally been used as the criterion for the maintenance requirement, is larger than the so-called obligatory nitrogen loss. An attempt was made, in the light of the information available at the time, to determine the magnitude of this difference.

The second advance was the clear recognition that in estimating requirements for groups, the principles are not the same for energy as for protein. For energy, an individual's intake must match his output if he is to remain in a steady state, and it is accepted that physiological mechanisms exist by which this balance is normally maintained, albeit not each day. For protein, in contrast, there is no evidence of a regulatory mechanism that matches intake to requirement. However, there is also no reason to suppose that an intake moderately larger than the individual's physiological need will be harmful, at least within fairly wide limits. Together, these considerations led to an approach that described on the one hand an *average* requirement for energy and, on the other hand, a *safe level of intake* for protein. The safe level for a population was defined as the average protein requirement of the individuals in the population, plus 2 standard deviations (SD). There was little information about the variability of individual requirements, and the 1971 Committee accepted an estimate of 15% for the coefficient of variation.

In 1975 FAO and WHO convened an informal gathering of experts (*6*) to consider problems that had arisen in the application of the report of the 1971 Committee. They considered a number of situations in which it was thought that the 1973 report had been misused or was incomplete. They also recognized that the emphasis placed by previous groups of experts (*2–4*) on specifying nutrient requirements for healthy populations was an ideal. They began to tackle some of the problems that arise in reconciling this ideal with reality. Of particular importance are two questions relating to children: adjustments of requirements for deficits in growth and for the effects of frequent infections.

In 1978 a further informal meeting of experts continued the review process begun in 1975 (*7*). This group identified five main areas of uncertainty, particularly in relation to protein requirements.

(*a*) It has been questioned whether the 1973 recommendations on adult protein requirements, based largely on data from healthy, well-nourished individuals, are realistic for developing countries.

(*b*) Since 1971 a number of studies had re-emphasized the important relationship between energy intake and nitrogen balance, and had suggested that protein requirements determined from balance measurements at high levels of energy intake may be erroneously low.

(*c*) It was considered that in previous reports too little attention had been given to the requirements of women, adolescents, and older children, and that further review was needed of the requirements for pregnant and lactating women and old people.

(*d*) More information was needed on the ability of local diets to meet protein needs, and on the extent to which amino acid scores and biological assays in rats give realistic estimates of the protein values of human diets.

(*e*) A preliminary attempt was made to estimate the extra protein and energy requirements for compensatory growth in malnourished children and for recovery from frequent infections.

Furthermore, the important question was raised of the practical relevance of the traditional criteria by which requirements are determined, i.e., nitrogen balance for protein and the maintenance of body weight for energy. The group pointed out that the gaps in knowledge that it had identified were all within the framework of traditional approaches to the problem of determining protein requirements. It raised the question whether adaptation to low protein intake involves any disadvantages, provided that the intake is sufficient to achieve balance and normal growth. Similarly, weight maintenance, the usual criterion of energy balance, takes no account of whether body weight is optimal, or whether the "requirement" allows for a socially adequate level of physical activity.

The 1978 group therefore concluded that a further full-scale expert consultation was necessary for two reasons: (*a*) enough new knowledge had accumulated since 1971 to justify trying to fill some of the gaps in the 1971 Committee's report; and (*b*) account had to be taken of the capacity of man to adapt to different nutritional and environmental conditions. The concept of adaptation is not easy to define, and it is even more difficult to determine the limits within which an adaptation may be regarded as successful. Moreover, if it is accepted that as a result of adaptation requirements may differ in different situations, it may be inappropriate to aim for uniform international standards. It was therefore necessary to re-examine the concepts on which requirements are estimated and, as far as possible, to relate them to the functional capacity both physical and mental, of the individual in a particular society—in other words, to ensure that the requirements relate to the actual conditions of life.

It follows from this line of thought that throughout the process of determining protein and energy requirements the question "requirements for what?" has to be borne in mind. Acceptance of this view demands a closer liaison between biologists, who are concerned with the physiological basis for estimating requirements, and social scientists, who are concerned with the practical application of those estimates.

Ideally, a group set up to advise on requirements should include representatives of a wide range of disciplines. However, this was not considered to be feasible at the present time. As the 1978 report (*7*) shows, in spite of all the previous work that had been done, many difficult biological and statistical problems remained, and it was necessary to tackle these first. The work of the present Consultation should perhaps be regarded as preparatory to a more completely integrated approach in the future. The present report does, however, identify some of the principles that should be considered when applying estimated requirements. Unlike the report of the 1971 Committee, this report does not include detailed recommendations on application of the estimates at the national level.

The primary task of these committees or other expert groups (*1, 6, 7*) has been to provide the United Nations agencies with tools for addressing practical questions, such as assessment of the adequacy of food supplies and targets for food and nutrition policy. Past reports have also influenced the decisions of national committees in developing estimates of requirements appropriate to local conditions and applications.

At the same time, the international meetings of experts have been extremely productive in generating new ideas and stimulating new research. This is particularly apparent in relation to protein requirements; each successive meeting, building on the work of its predecessors, has identified gaps in current knowledge which research workers in many countries have done their best to fill. The identification of problems and the stimulation of further research is an extremely important function.

There is a widespread view that the limiting factor in the solution of the world's nutritional problems is not the lack of knowledge but the inadequacy and maldistribution of resources. The reports of the expert meetings over the years make it very clear that this conclusion is not entirely justified. Resources are indeed limited, but to use them as efficiently as possible requires a sound basis of knowledge. For this reason the present report, like its predecessors, ends with a section on the needs for future research.

One of the clearest indications of the need for continuing research is the fact that the recommendations of each successive meeting, including the present one, differ in some respects from those of its predecessors. Each meeting, moreover, tends to emphasize different aspects of the problem. The report of the 1971 Committee included, in its introduction, an historical account illustrating the evolution of ideas and knowledge. These changing ideas may cause problems for planners and policy-makers, but it has to be accepted that we can only approach our aim by a process of successive approximations.

Because of advances in our knowledge during the past decade, it is inevitable that the recommendations in this report should differ in some important respects from those of the 1971 Committee. That committee built up its estimates of energy requirements on the basis of a reference man and woman who were "arbitrarily selected convenient starting points for extrapolation ... and ... not intended to suggest ideal standards. They were originally chosen as being representative of groups of men and women whose food consumption and energy expenditure had been carefully studied" (*1*, p. 23). In the present report there is some change of emphasis. The concept of the reference man or woman seems to be unduly restrictive once it is recognized that in the world as a whole there is a wide range in both body size and patterns of physical activity. The object of the tables in this report is to reflect this wide range, so that the user can choose the values that are most appropriate to his or her conditions.

As a matter of principle we believe that estimates of energy requirements should, as far as possible, be based on estimates of energy expenditure, whether actual or desirable (see section 4). To determine requirements from observed intakes is largely a circular argument, since in both developing and developed countries actual intakes are not necessarily those that maintain a desirable body weight or optimal levels of physical activity, and hence health in its broadest sense. However, it has not been possible to follow this principle in the case of children, because we do not have enough information about their energy expenditure. We have attempted to give some detailed examples of divers patterns of physical activity in different age and sex groups in the hope that they may provide useful guidelines for the application of requirement estimates.

In formulating requirements for protein we have followed the 1971 Committee in trying to establish two reference points where knowledge may be regarded as reasonably reliable. The first is the maintenance protein requirement of the young child; the second is the requirement of the young male adult—a group that has been studied intensively in the last 10 years (see section 6). We still, however, have much less direct information than is desirable about other age groups. It has therefore been necessary, as in previous reports, to make indirect estimates of their protein needs by interpolation. In addition, previous meetings have emphasized the need to correct the estimated protein requirement for differences in protein quality. The present Consultation concludes that few natural diets provide insufficient amounts of essential amino acids, except for infants and preschool children. On the other hand, it is apparent that more attention should be given to the digestibility of the proteins in a mixed diet, especially in the diets of people in developing countries. As pointed out by the 1975 informal gathering of experts (*6*), this subject was relatively neglected by the 1971 Committee, but it is clear that the availability of dietary protein for all age groups can be significantly affected by digestibility, and that protein requirements should be appropriately adjusted for increased faecal losses of nitrogen.

The Consultation was conscious of the responsibility involved in proposing these changes, which may well have important implications for planners. Since the knowledge available was seldom adequate for strict conclusions, the Consultation had to base its estimates on its judgement of the scientific evidence available together with past experience. The conclusions of the Consultation are as well grounded as is possible given the present state of knowledge. Future experience will show how realistic they are.

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2. ENERGY AND PROTEIN REQUIREMENTS—SOME UNIFYING CONCEPTS

A number of problems that have arisen in the application of earlier reports can be attributed to incomplete understanding of the meaning of requirement estimates and of the conceptual framework linking energy and protein requirements. Some principles underlying the application of these concepts to practical situations are discussed in sections 10 and 11.

As defined and used in this report, estimates of requirements relate to the maintenance of health in already healthy individuals. Health is understood to include patterns of activity that are judged to be consistent with satisfactory physiological and social function.

2.1 Definitions

The requirements for energy and protein of an individual are defined in the following terms:

Energy. The energy requirement of an individual is the level of energy intake from food that will balance energy expenditure when the individual has a body size and composition, and level of physical activity, consistent with long-term good health; and that will allow for the maintenance of economically necessary and socially desirable physical activity. In children and pregnant or lactating women the energy requirement includes the energy needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health.

Protein. The protein requirement of an individual is defined as the lowest level of dietary protein intake that will balance the losses of nitrogen from the body in persons maintaining energy balance at modest levels of physical activity. In children and pregnant or lactating women, the protein requirement is taken to include the needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health.

All requirement estimates refer to needs persisting over moderate periods of time. The corresponding intakes may be referred to as "habitual" or "usual", to distinguish them from intakes on a particular day. However, as a matter of convention and convenience they are expressed as daily rates (of intake). However, there is no implication that these amounts must be consumed each day.

The way in which requirement estimates should be applied when health or reasonable freedom from infection cannot be assumed, is considered in section 9.

There are important physiological differences between the requirements for energy and protein, as defined above. For energy, it is usually considered that once the level of body weight and physical activity has been fixed and the appropriate growth rate defined, there is only one level of intake at which energy balance can be achieved; in consequence, this becomes that individual's requirement for energy. Even if some degree of adaptation is possible, as discussed in section 4, it is likely that this range is fairly narrow. If the intake is either above or below the requirement, defined in this way, a change in body energy stores is to be expected unless energy expenditure is correspondingly altered. If such changes in expenditure do not occur, the energy store, mainly in the form of adipose tissue, will increase when the intake exceeds requirement and decrease when it is below requirement. It is clearly contrary to experience to suppose that for each individual there is one fixed set-point for body weight and adipose tissue mass compatible with health. In fact, we recognize that for any individual there is probably a range of acceptable body weights, and this also applies to the individuals in a group (section 3.5). However, if the imbalance is too great, or continues over long periods, the resulting changes in body weight and composition can be detrimental to function and health. Consequently, there may be risks associated with intakes either above or below actual requirements.

For protein, the requirements of individuals are also expressed in terms of the amount of dietary protein needed to prevent losses of body protein and to allow, where appropriate, for desirable rates of deposition of protein during growth and pregnancy. In this respect, the requirements of the individual for both protein and energy are analogous. However, in contrast to energy, if more protein is ingested than is needed for metabolic purposes, essentially all the excess is metabolized and the end-products are excreted, since protein is not stored in the body in the way that energy is stored in adipose tissue. Furthermore, again in contrast to energy, no detrimental effect has been identified with intakes of protein moderately above the actual requirement. For an individual, the range between the intake that is just sufficient to compensate for losses (or permit growth) and intakes that are associated with harmful effects is therefore wide. The individual's requirement is thus defined as the lower end of this range (see section 5 for a more complete discussion). As will be seen in the next section, this fundamental biological difference between energy and protein has important consequences for describing the distribution of requirements among the individuals of a group.

2.2 Individuals and groups

After defining the requirements of an individual, the next step is to extend this definition to those of a group. Estimates of requirements are derived from measurements on individuals. Actual measurements on people of the same sex and of similar age, body size, and physical activity are in practice grouped together to give the average energy or protein requirement of that set of people, together with a measure of their variability. These results are then used to predict the requirements of other individuals or collections of individuals who have the same characteristics, but on whom measurements have not been made. Such a collection of similar individuals may be referred to as a *class*.

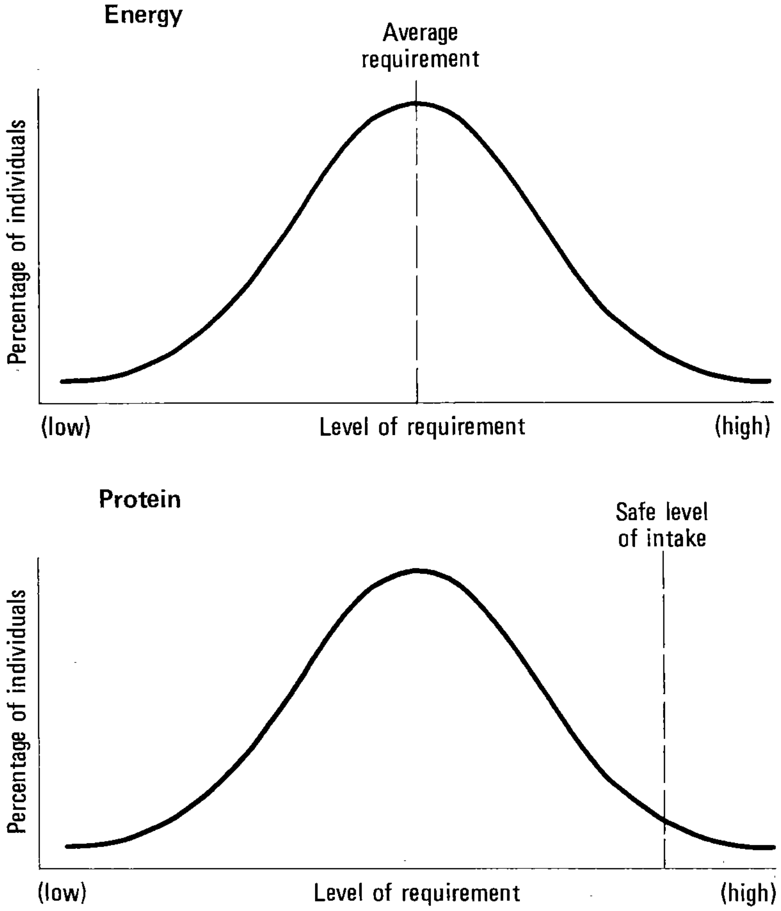
The characteristics of the class are that obvious factors that may affect requirements—age, sex, weight, etc.—have been matched. However, in spite of the matching there remain many unknown factors producing variation between individuals, so that there is a distribution of requirements within the class. Changes in the variables that characterize the class will involve a change in the average requirement and therefore a change in the position of the distribution.

These concepts apply to both energy and protein requirements. In tabulating estimates of requirements for a particular class of individuals, it is convenient to describe their distribution by a single statistic, the *descriptor,* which differs for energy and protein for the reasons outlined in the previous section.

For a class of similar individuals, the descriptor of energy requirements is the *average* of the individual requirements, without specific provision for the known individual variation in requirement.

The descriptor of the protein requirement of a class of similar individuals is the *safe level of intake,* an amount that will meet or exceed the requirements of practically all the individuals in the group, explicitly taking into account individual variation in

Fig. 1. Comparison of average requirement for energy and safe level of intake for protein[a]



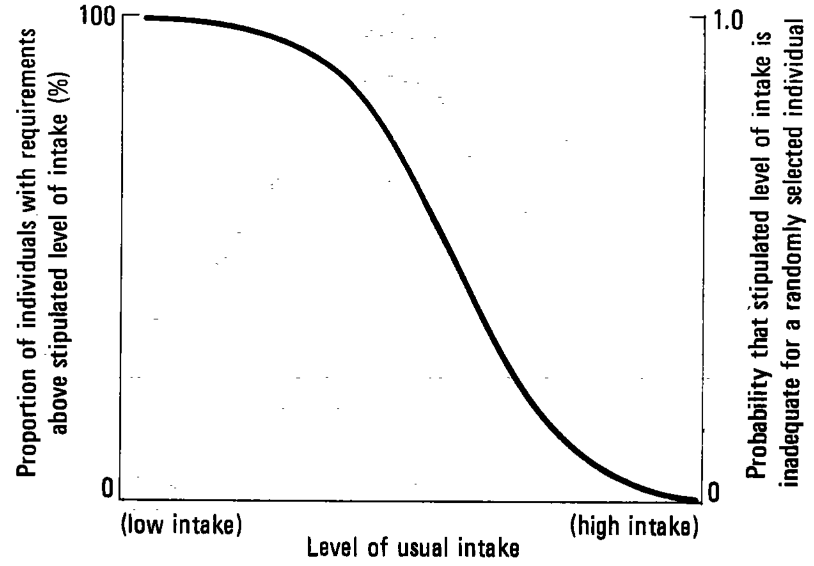
[a] It is assumed in each case that individual requirements are randomly distributed about the mean requirement for the class of individual and that the distribution is Gaussian.

requirement. Following the lead of the 1971 Committee (*1*), the safe level is defined as the average requirement + 2 standard deviations.

The contrast between the two descriptors is illustrated in Fig. 1, in which it is assumed that the statistical distributions are Gaussian, although the principles hold for other types of distribution.

Fig. 2 shows the proportion of randomly selected individuals whose requirement would not be met when a particular level of

Fig. 2. Derivation of a probability statement from a knowledge of the requirement distribution



The curve represents the cumulative distribution of requirements. Intake refers to an *assigned* level of intake for a randomly selected individual and it is assumed that there is no correlation between intake and requirement among similar individuals. If the individual selects food to meet nutrient or energy requirement, the probability statement must be modified as discussed in the text.

intake is provided. The curve describes the probability that the intake would or would not meet an individual's requirement.

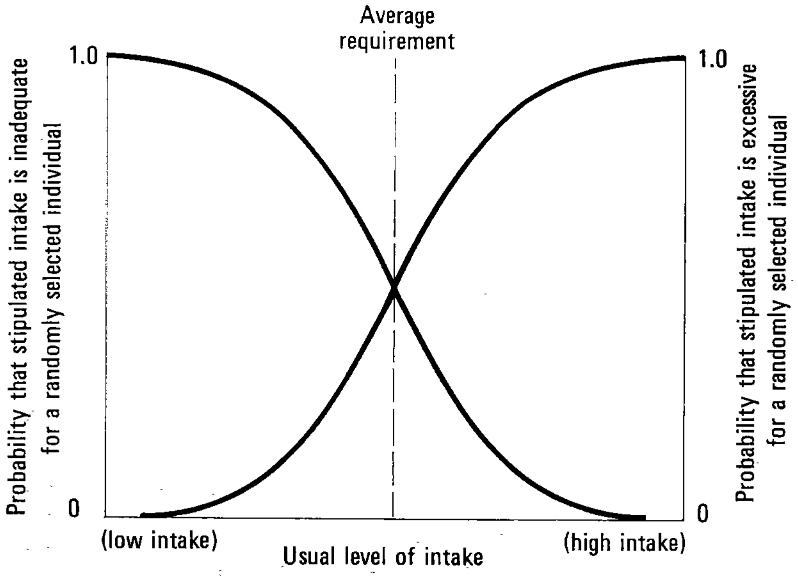
In a similar way, one can consider the probability that a high intake will be associated with detrimental effects for a randomly selected individual. As noted above, there is a major biological difference between energy and protein in this respect. For energy, potentially detrimental effects are associated with long-term intakes only slightly above the individual's requirement. In this case, there are two probability curves (meeting of requirements and causing adverse effects) that overlap, as shown in Fig. 3(A). For each individual there is a range of protein intakes above requirement at which no detrimental effect is known to occur. The two probability curves are thus separated, as shown in Fig. 3(B).

From these curves it will be apparent that if all individuals consumed protein at levels equal to, or moderately greater than, the "safe level of intake", there would be very little chance that any would have inadequate intakes. At the same time, unless the intakes were considerably above this level, there would be very little probability of harmful effects. The 1971 Committee (*1*) chose to identify this lower point as the single descriptor of the distribution of requirements for protein. In 1971 it was called the "safe level of intake"; in earlier reports it had been called the "recommended intake". The present Consultation chose to retain the term "safe level of protein intake".

From Fig. 3 it is apparent that a similar approach could not be followed for energy. The level of energy intake that assures a low probability of inadequate intake (average requirement + 2 standard deviations) is the same level that implies a high probability of a harmfully high intake for most people. In agreement with earlier reports, this Consultation concluded that the only descriptor that could be safely adopted is the estimated *average* requirement of a group of any class of individuals. This is appropriate in another respect. Most people have the ability to select their food intake in

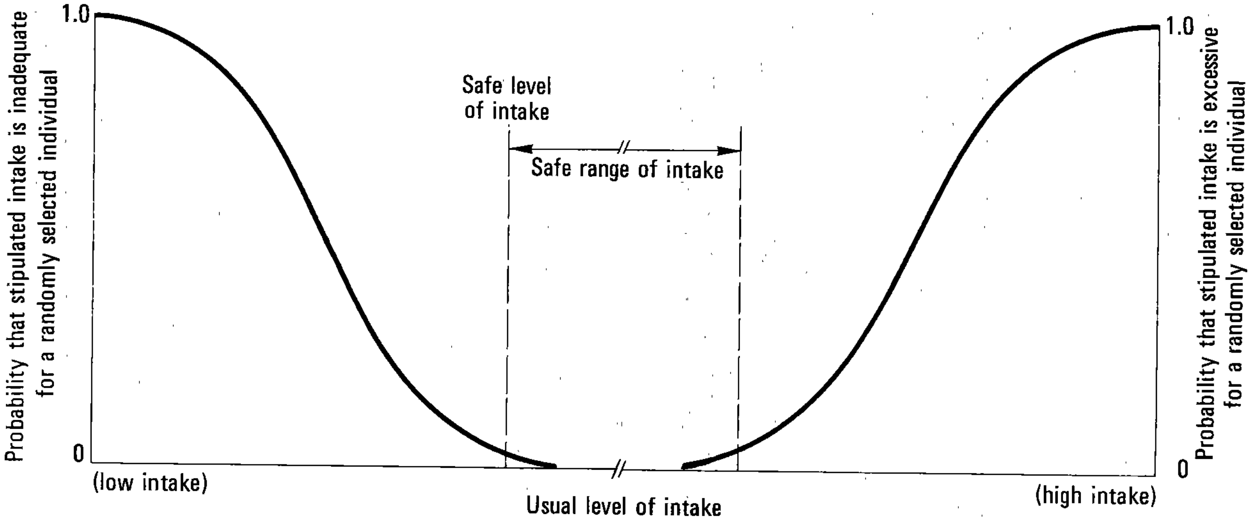
Fig. 3. Probability that a particular intake is inadequate or excessive for a randomly selected individual with regard to energy intake (A) and protein intake (B)

A. Energy



B. Protein

Fig. 3 (*continued*)



In the case of energy, the two probability curves overlap. In the case of protein the curves are separated by a "safe range of intake" that will be associated with low probabilities of either inadequacy or excess for almost all individuals.

accordance with their energy requirement over the long-term, since it is believed that regulatory mechanisms operate to maintain a balance between energy intake and energy requirement over long periods of time. This implies that one would expect there to be a correlation between energy intake and energy requirement among individuals if sufficient food is available in the absence of interfering factors. In the examples cited above (Fig. 3), food intake was taken as fixed at each level, and the probabilities of inadequacy or excess at that level for a random individual were considered. If self-selection is allowed to operate, it is to be expected that individuals will make selections according to energy need and the probability of inadequacy or excess will be low across the whole range shown in Fig. 3. If the average energy intake of a class were equal to the average requirement of the class, almost all individuals would be at low risk because of processes regulating energy balance and the resultant correlation between intake and requirement. Thus, when one is considering the requirements of classes, the estimate of average requirement is an appropriate descriptor for the distribution of requirement.

For protein, there is very little evidence of a correlation between intake and requirement among individuals consuming self-selected diets. Thus, the probability descriptions presented in Fig. 3 apply whether the random individual consumes a self-selected diet or is given an arbitrarily selected amount of protein. Consequently, if the average protein intake of a group is equal to the *average* protein requirement of that group, it cannot be assumed that the probability of inadequacy will be low for most individuals. On the contrary, this would be an "unsafe" situation.

These considerations influenced the 1971 Committee (*1*) in selecting the particular descriptors of the requirement distributions for energy (average) and for protein (safe level). The bases for the decisions were discussed in abbreviated form in that report, although the implications may not have been sufficiently emphasized for all of its users.

REFERENCES

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3. CONSIDERATIONS COMMON TO THE ESTIMATION OF ENERGY AND PROTEIN REQUIREMENTS

3.1 Adaptation

In the context of nutrition, a working definition of adaptation might be: "a process by which a new or different steady state is reached in response to a change or difference in the intake of food and nutrients". The word "new" includes the individual who is responding to a change, e.g., when a subject in a balance study moves from a high- to a low-protein intake. The word "different" is appropriate when comparisons are made between individuals or groups who are habitually exposed to different environmental or nutritional conditions. It might be useful to distinguish these as short-term and long-term adaptations.

Three general points are important in relation to both types of adaptation.

(*a*) The concept of a steady state is relative. No one is ever in an absolutely steady state, either in body weight or in nitrogen balance. During the day, when food is being eaten, nitrogen balance is positive; during the night, in the absence of food, it becomes negative (*1*). Over 24 hours these fluctuations even out. The situation is precisely analogous to the oxygen debt incurred during strenuous exercise, which is made up during rest. The time-scale over which a state may be considered steady will vary for different functions. It is also clear that in biological systems no so-called steady state is completely stable. This is illustrated by the slow changes in body composition and function that occur as adults age.

(*b*) Adaptations may be of fundamentally different kinds—metabolic, biological/genetic, and social/behavioural. The response to a change in protein intake is one of the best worked out examples of a metabolic adaptation, but even in this case we do not know the limits of human adaptability. Metabolic adaptations to different levels of energy and protein intake will be considered in the appropriate sections (4 and 5).

Reduction in physical activity as a consequence of a reduced energy intake could be regarded as a behavioural adaptation, with both good and bad effects. For example, the energy intakes of children may be adequate to support satisfactory growth rates, but only at the expense of a reduction in total energy expenditure, notably through less physical activity (*2, 3*). The result is to impair the child's capacity for exploration and play, and hence his mental, functional, and social development. This question is considered in more detail in section 4.

It has often been suggested that a decrease in body size might be an advantageous adaptation to shortage in food supply. The determinants of body size are complex and depend upon both environmental and genetic factors. In developing countries large numbers of children are small for their age compared with the NCHS standards (see section 3.2.1). This reduction in linear growth ("stunting") is the result of environmental factors because it is reversible under favourable conditions. Whether it represents a handicap is hotly debated (see sections 3.2 and 3.4). It has also been suggested that selection might occur in favour of those who are genetically smaller and hence have lower needs. A full analysis of the significance of differences in body size would have to take account also of the secular changes that have occurred in a number of countries (*4, 5*) and of the established relationship between the heights of parents and their children (*6*).

(*c*) It follows from these considerations that adaptation implies a range of steady states and it is impossible to define a single point within the range that represents the "normal". Different adapted states will carry different advantages and penalties. A decision about which is optimal or preferable can only be made in the light of a particular set of values. If the criteria are life expectancy and freedom from disease in the early years of life, then perhaps the nutritional state in industrialized societies might be preferred to that of developing countries, but there may be other criteria of optimal functional capacity.

The same point was made in the report of the 1971 Committee (*7*), in an apt quotation from Atwater & Benedict (*8*): "One essential question is, what level is most advantageous? The answer to this must be sought not simply in metabolism experiments and dietary studies, but also in broader observations regarding bodily and mental efficiency and general health, strength and welfare".

The concept of a range of adapted states, each with advantages and disadvantages, produces a dilemma: it implies respect for different biological and cultural situations, but it may also encourage the acceptance of double standards and the endorsement of the *status quo*. To quote again from the report of the 1971 Committee: "when supplies are insufficient and purchasing power is low, consumption is likely to be less than requirements. In such circumstances 'what is' will not be 'what should be' " (*7*, p. 15).

It follows that requirements cannot be specified on physiological grounds alone, such as the need to maintain balance. Consequently, in this report value judgements are made about the state that it is considered desirable to achieve. It is not expected that all those who use this report will make the same judgements. Our aim, therefore, has been to set out clearly the principles and the measurements on which the estimates are based, and to indicate as far as possible the areas of uncertainty, so that the estimates can be applied in a flexible way in different situations.

3.2 Body size: reference standards for children, adolescents, and adults

Body size is the major determinant of the absolute requirements for energy and protein. Variations in size are probably more significant quantitatively than the metabolic adaptations discussed in later sections. It is therefore necessary at the outset to define acceptable ranges of body size.

3.2.1 *Children*

Although the energy and protein requirements for the process of growth are relatively small compared with those for maintenance, except in the young infant, satisfactory growth is nevertheless a sensitive criterion of whether needs are being met. Therefore, the definition of satisfactory growth is the first step in estimating the requirements of infants and children. An example of the dilemma mentioned above is whether reference standards for the growth of children in industrialized countries should be accepted as universally relevant or whether local standards should be used (*9*). Children in many developing countries are smaller at birth than those in industrialized countries and grow at a slower rate during infancy and early childhood. The evidence suggests that in young children these differences are due primarily to environmental factors, including inadequate nutrition, and that genetic and ethnic factors are of lesser importance, so that young children of different ethnic groups should be considered as having the same or similar growth potential (*10–12*).

Even in a healthy privileged population there is a wide range of variation in the size of children. In such a population there is no indication that differences in size *per se* are related to health, wellbeing, or physiological function. However, in communities where children's growth is limited by environmental factors, there is evidence of an association between functional impairment and deficit in linear growth (*13*). In such situations, it is extremely difficult to separate the effects of undernutrition from those of other aspects of social deprivation. Therefore, it remains a matter for further research how far small size in children represents a handicap or an adaptation, whether minor limitations of genetic growth potential are harmful, and whether maximum growth is necessarily an indicator of optimal nutrition (*14*).

Nevertheless, the Consultation feels it desirable that the growth potential of children should be fully expressed, and estimates of energy and protein requirements should allow for this. Estimates of the requirements of children up to 10 years are therefore based on the reference growth standards published for international use by WHO (*15*), which are derived from the United States National Center for Health Statistics (NCHS) (*16*). The use of this particular reference population is recommended on the basis of a number of criteria (*17*). These standards are summarized in Annex 2(A).

Surprisingly, in contrast to adults (see below), there appear to be no recommendations for children concerning the ranges within which weight or height at any given age may be regarded as satisfactory. This is partly because information about the risk attached to given degrees of deficit is only just becoming available (*18, 19*), and partly because children start with different birth-weights, and therefore their attained weights will continue for some time to be above or below the median. In epidemiological studies of childhood undernutrition it is conventional to accept −2 SD from the median as the cut-off point between "normal" and "malnourished", corresponding approximately to the 3rd centile or to 80% of the median for weight (*15*) and 90% for height. Similarly, +2 SD in weight for height may be taken as a cut-off point for obesity.

In relation to growth, two further points must be taken into account. Previous committees have based their estimates of the daily requirements for growth on increments in body weight of the reference population over intervals of 3 months for infants below 1 year and intervals of 1 year for older children. This procedure assumes that growth occurs at the same rate from day to day. It must be recognized that this is not so, and that even in normal children free from infection growth occurs in spurts. As a result, the variability in weight gain over short periods such as one month is extremely high. For example, in two longitudinal studies from birth to 3–6 months, the coefficient of variation of weight gain over 4-week periods was approximately 37% (*20, 21*). The reasons for this variability in the rate of weight gain are not clear. The data of Fomon (personal communication, 1980) show that it is greater than the variability in energy intake. One factor, therefore, may be day-to-day fluctuations in physical activity. From the point of view of protein requirements, the phenomenon could be regarded as analogous, on a longer time-scale, to the metabolic differences that have been observed between the day, when food is consumed, and the night, when it is not. Studies on adults have shown that during the night there is a negative nitrogen balance that is cancelled out by a positive balance during the day (*1*). In children it has been suggested that growth occurs in spurts in relation to food intake (*22*).

The variability in growth would not affect requirements averaged over a period of time if it were a consequence simply of fluctuations in food intake, so that intake and rate of growth each day were exactly matched. It seems unlikely, however, that this is the full explanation. Since this exact matching does not happen, the effect of the variability in growth may be to increase the growth component of the requirement, as a reduction in growth over one period will have to be compensated by an increased growth rate later on. As discussed in section 6.3.2, it is extremely difficult to estimate the quantitative effect of this variability in growth rate.

A second question that should be raised, although it cannot at present be answered, results from the fact that all allowances for growth are based on increments of body weight. It is conceivable that growth might be limited by special requirements of particular tissues; for example, the relative amounts of energy and protein needed to achieve a given gain in body weight might not be the same as the amounts needed to secure an appropriate increase in height. This is a subject on which further research is needed.

3.2.2 *Adolescents*

The desirable heights and weights of children over 10 years of age present special problems, because there is considerable variation between individuals and groups in the timing of the adolescent growth spurt, which starts at different calendar ages in boys and girls (*6*).

Furthermore, if children have been growing slowly from infancy, as happens in many developing countries, by 10 years of age the gap between their actual weight and their expected weight, based on that of adolescents in industrialized countries, will be very large. It is not known whether extra food at this stage can increase the extent and duration of the pubertal growth spurt.

For these reasons it is considered more realistic, after the age of 10 years, to relate requirements to the appropriate weight for height rather than weight for age. In order to maintain uniformity with the reference values for the earlier years of childhood, the standards published by WHO for height up to 18 years have again been chosen, but they do not include values of weight for height beyond 10 years. To provide these values the Consultation used data from a large sample of children measured in the United States of America earlier in this century (*23*). Annex 2(B) gives the median weight for height of boys and girls at each age, not only at the median height of the standards published by WHO, but also at different heights. By using actual height and median weight for height, it is possible to allow for the fact that puberty begins at different ages in different groups of adolescents. Again, as with younger children, there are no clear recommendations about the "acceptable" range of weight for height.

3.2.3 *Adults*

Adult groups in various parts of the world show substantial differences in height (*24*), and height variations are also common within countries and races.

In general, there is no reason to suppose that adults of either short or tall stature have a health risk attributable to their stature, except perhaps in relation to pregnancy and childbirth (*25*), and therefore no attempt is made in this report to define the height of a healthy reference population of adults. However, body weight, when expressed in relation to height, does influence health, and a range of desirable or acceptable weights for height has been proposed (*26*). These values, derived from actuarial analyses (*27*) and prospective epidemiological studies in Western communities, are set out in Annex 2(C). The upper limit of the acceptable range, at which there is an increased risk to health, has been reasonably well defined.

Unfortunately, the same cannot be said for the lower limit. It has been claimed (*28*) that the range has been set too low, and that it may, in fact, be beneficial to have a weight for height in excess of the desirable range shown in Annex 2(C). However, the evidence in support of this claim may be criticized: for example, the apparent increase in risk associated with being moderately underweight may, in the populations studied, be due to an association with smoking or chronic disease (*29*).

Long-term prospective studies on large numbers of adults in developing countries are not available. It must be recognized that in communities subject to infections, periodic food deprivation, and high energy demands for physical activity, a higher body weight than the average suggested in Annex 2(C) could be advantageous. At present the average weight of adults in many countries is below the mid-point of that range, and sometimes even below the lower limit (*24*). There is no direct evidence that this in itself is either beneficial or harmful. More information relating body weight and composition to health risk in these communities would be valuable. In the absence of such information, the range of weight for height shown in Annex 2(C) was accepted by the Consultation as appropriate for all populations.

A useful simplification is to express the weight for height as the body mass index (BMI) (Wt/Ht^2, or Quetelet's index), since this function gives a measure of weight for height that is largely independent of actual height (*30*). The justification for using this index is twofold: the point made above, that stature is not considered to be related to health risks; and the point discussed in section 6 that, except in the very young and the elderly, height appears to have little effect on energy or protein requirements independently of its relationship to weight.

3.3 Body composition

Estimates of requirements based on body weight are an approximation, since they do not take account of differences in body composition, which will determine true requirements. In recent decades the emergence of methods for estimating some body components in living subjects has resulted in observations on several thousand people ranging from newborn infants to the very old. At birth the neonate averages 14% body fat, which rises to about 23% at 12 months and declines to 18% at 6 years of age (*31*). During this period girls have slightly more body fat than boys (*32*), and this difference becomes more pronounced after 6 years (*33*). During adolescence the difference in the body fat content between the sexes becomes strikingly accentuated (*34–36*) and persists throughout adult life as shown by differences in the thickness of the subcutaneous fat layers (*37*). There is evidence that body composition is also influenced by genetic factors, since obesity tends to be familial (*38*) and monozygous twins are more concordant in fatness than dizygous twins (*39*).

Adolescence is also characterized by a major sex difference in the rate of acquisition of lean weight. Boys show a rapid and sustained spurt in lean weight, whereas there is a modest acquisition of body fat in the early phase of puberty, followed by a decline. In contrast, girls have a smaller spurt in lean weight, but they acquire more body fat. In adolescent boys the time of the spurt in lean weight has been found to coincide with the most rapid growth in height (*36*), and to continue until 20–25 years of age (*34, 35*), whereas in girls the pubertal increase in lean weight ceases by about 18 years, in keeping with the marked decrease in the rate of gain in stature after menarche (*6*). During the second decade of life boys thus double their lean weight, while the increase in girls is only 1.5-fold. The end result at maturity is a fat-free weight of about 60 kg in males averaging 70 kg total body weight, and 42 kg in females averaging 63 kg. The variability in lean weight is less than that of total body weight (*35, 40*).

The adult years are characterized by a decline in lean body mass in both sexes, which becomes obvious by the age of 40; by 85 years the lean body mass has reached a value about three-quarters of that characteristic of the young adult (*35, 41–43*). Simultaneous measurements of body nitrogen by neutron activation and body potassium as ^{40}K show that, with advancing age, more potassium than nitrogen is lost (*44*), implying that the potassium-rich muscle mass is especially reduced. The relative loss of potassium is about 10% between the sixth and eighth decades (*45*). Autopsy data (*46*) confirm that subjects over 70 years of age have 40% less muscle than young adults, with a smaller reduction in the mass of visceral organs. Preferential loss of muscle with aging is also demonstrated by the decline in creatinine output (*47*) and the fall in 3-methyl histidine output (*48*). This age-related loss of lean body mass is commonly accompanied by an increase in body fat. Consequently, in relation to body weight, the lean tissue content of the body declines with age, and this accounts in part for a progressive fall in basal metabolic rate in relation to body size (*49, 50*). In the elderly there is a decrease in the proportion of skeletal mass, as well as muscle (*51*).

Within the lean body mass there are also differences in the proportion of various tissues at different ages. From birth to maturity the brain increases its mass 5-fold, the liver, heart, and kidneys, which are even more metabolically active, increase 10- to 12-fold, while muscle multiplies its mass by about 40-fold.

3.4 Physical fitness and functional capacity

Estimates of requirements for energy and protein are based primarily on metabolic and balance studies of limited duration. However, the estimated requirements should be enough to maintain health and sustain optimal bodily function, including physical and mental fitness.

During growth, in addition to the increases in weight and height, there are marked functional changes. In boys, aerobic capacity and heart volume in relation to lean body mass increase up to the age of 14–15 years (*52, 53*). The natural peak in functional capacity coincides with high levels of spontaneous physical activity, and estimates of requirements must allow for this. Conversely, in the fourth to the fifth decade of life aerobic capacity starts to decline, with decreasing physical activity and energy requirements.

Intakes of energy or protein above as well as below those needed for optimal function may be detrimental if they exceed the adaptive capacity of the organism. Excessive energy intakes lead to obesity, with reductions in cardiorespiratory efficiency, physical performance, and endurance.

It has already been suggested (page 23) that stunting in linear growth may represent an adaptation that does not necessarily present any health hazard beyond early life. For example, cardiorespiratory function, physical performance, and muscular strength were found to be significantly better in stunted Tunisian children from a poor socioeconomic group than in children from affluent families, whose growth was closer to that of the standard in developed countries (*54*). Similarly, Italian children from poor families performed better in physical fitness tests than their counterparts from more prosperous families, in spite of their smaller size and lower habitual energy intakes (*55*). These findings suggest that habitual physical activity is a more important determinant of fitness than is body size *per se*. Nor do the effects of small stature necessarily carry penalties in adult life (*56*) except for tasks requiring a particular body build and strength. Thus high aerobic capacity related to body weight was found in Indian miners with very low weights and heights compared with their counterparts in other countries (*57*). On the other hand, in another study in India low weight and height were significant handicaps for obtaining employment in agriculture (*58*). Therefore, while stunting in height is a rather sensitive marker of socioeconomically disadvantaged populations, the consequences need to be carefully evaluated for evidence of any functional handicap.

3.5 Expression of requirements in relation to body weight and age

In healthy people within the ranges of acceptable weight for height or weight for age proposed in section 3.2, the main determinants of requirements for both energy and protein are body weight and age, and in the case of energy, physical activity. Further considerations, discussed in section 9, apply for people outside these desirable ranges.

3.5.1 *Relation to body weight*

Protein. Within a given age range, the requirement for protein per kg of body weight is considered to be constant. Therefore, the *primary expression* of protein requirement is in grams of protein per kilogram. This principle applies to all ages, although absolute additions, in units of grams of protein per day, are made for pregnancy and lactation.

Energy. For energy the position is more complicated, because at a given age the main component of the energy requirement, the basal metabolic rate (BMR) varies not only with absolute body weight but also per kg. The total energy requirement per kg, therefore, cannot be taken as constant. Hence the *primary expression* of energy requirement is the total requirement per person, derived from that person's body weight.

With adults less than 60 years old the effect of age is relatively unimportant, since at a given weight the BMR decreases by only about 1% per decade. With children the change of BMR per kg with age is much greater—about 5% per year between 3 and 10 years. At present, we do not know to what extent this reflects an age-related change *per se,* or age-related changes in body weight. However, for this report the question is not of practical importance, since the BMR has not been used for estimating energy requirements in children below the age of 10 years.

The energy requirements of adolescents are treated in the same way as those of adults.

If at each age weight is the main determinant of requirements, the question then arises, what weight should be used? Within the acceptable range, many people will have weights that differ by 10% or more from the median. If the actual weight is used, it will tend to maintain the *status quo.* If the median of the reference range is used, the result will have a normative effect. The existing needs of those who are at the lower end of the weight range for age or height will be overestimated and the needs of those at the upper end will be underestimated. If the requirements so calculated are fulfilled, there will be a tendency for weight to move towards the median. This is what is meant by the term "normative", as used in this report. It will be for the user to choose the most appropriate body weight for calculating requirements, depending on the circumstances and his aims.

3.5.2 *Relation to age*

For the tables in this report 6 main age ranges have been defined: 0–3 years; 3–10; 10–18; 18–30; 30–60; 60+; these are further discussed in section 3.6.1. The aim in selecting these ranges is to reflect the physiological characteristics of men and women, including the continual changes in rate of growth, body composition, physical activity, and patterns of food intake. These changes are particularly rapid at three periods—infancy, adolescence, and old age. Subdivisions are therefore necessary for infants and young children. In children up to 10 years of age no distinction is made between the sexes except for that which arises from differences in body weight. With adolescence important sex differences begin to appear in body composition and in the timing of the growth spurt (section 3.2.2). Since, however, the timing is very variable in relation to chronological age, subdivision into defined age groups would be impracticable. It would be desirable to divide further the age range from 60 years onwards, but unfortunately the information on which to base more accurate estimates related to age is too scanty.

3.6 Interpretation of tables of requirements

In section 2 the term "class" was introduced to take account of the variability that exists between apparently similar individuals. In practice this concept of a homogeneous class is not entirely realistic. For the purposes of tabulation it is necessary to group together individuals, according to age, weight for height, etc. The wider the ranges chosen, the less homogeneous such groups will be. The problem then is to decide on operationally useful ranges. No hard-and-fast guideline can be laid down. A large number of narrow ranges is more precise than a small number of wide ones, but also more complex. The ranges in many of the tables (e.g., section 8) have therefore been chosen as a compromise between convenience and precision.

The variability of requirements within a group defined by any chosen range will clearly be greater than in a completely homogeneous class. This has implications for calculating the requirements of the group as a whole which are of great importance for the application of requirement estimates, as discussed in section 11.

The requirements specified for each range in the tables represent those of the individual or homogeneous class whose weight for age or weight for height is at the mid-point of the range. Such estimates do not necessarily correspond with the average requirement of the group as a whole, since this will depend on the distribution of individuals within the group.

A particular problem, analogous to that discussed for the individual in section 3.5, arises if a group of people has a mean weight which is markedly different from the mid-point of the reference range. For example, the data collected by Eveleth & Tanner (*24*) show that young Indonesian adults had on average a body mass index (BMI) of 19, which is close to the lower end of the desirable range defined in section 3.2. It would be possible to specify the requirements of this group either on the basis of their actual average weight, or on the basis of the average acceptable weight for height (BMI 22), which would be about 15% greater. As in the case of the individual, the choice will depend upon whether or not the user considers the actual situation to be satisfactory.

There is, moreover, an additional complication. In such a group with a mean BMI of 19, there will be some individuals whose weight for height is below the limits of the acceptable range. In section 9 we discuss adjustments to requirement estimates for people whose weight for age or for height is outside those limits. The concept of an acceptable range implies that some action is necessary to improve the situation of those who are outside it and are therefore in an unacceptable position. With a mixed group, some of whom are "inside" and some "outside", there are again two choices of action: to concentrate on individual outsiders, or to take measures which will affect the whole group.

3.6.1 *Expression of age ranges*

Conflicting methods are often used for expressing the ages or age ranges to which values of body weight, BMR, etc., refer. In some tables, e.g., those of the NCHS, the value for body weight opposite the figure for 5 years, for example, means the weight at 5.0 years. Since few children will be measured exactly on their birthday, such values are usually obtained by interpolation. In tables in other reports, the entry for weight at 5 years may in some cases signify the average weight of children between 4.5 and 5.5 years (mean age 5.0 years), in others the average weight of children from 5 to 6 years (mean age 5.5 years).

For reasons of clarity and to comply with ordinary usage, age ranges (e.g., 5–6 years) are specified in this report, because this is how children are usually classified, for example in school.

When a value for body weight or height is given, it represents the value at the mid-point of the range, obtained by interpolation from the NCHS standards. The range 5–6 starts at 5 years, up to but not including 6 years. To write 5–5.99 implies an unrealistic degree of precision. Another useful solution is to designate the ranges as 5+, 6+, etc. (*32*).

When values (e.g., for BMR or protein requirement) are changing with age, it is clearly artificial to make dividing lines at particular ages at which abrupt changes are supposed to occur. In reality the values are continuous variables. If a more precise estimate is needed, it can be obtained by interpolation.

These are problems that relate more to applications than to the substance of this report, but it is necessary to outline them here in order to illustrate the different ways in which the figures and tables may be used.

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4. PRINCIPLES FOR THE ESTIMATION OF ENERGY REQUIREMENTS

4.1 General considerations

The energy requirement was defined (section 2) as the amount needed to maintain health, growth, and an "appropriate" level of physical activity. Using this definition it is impossible entirely to avoid value judgements on what is meant by health and appropriate activity. Values, and consequently decisions, may change under different conditions. The aim of this report is to provide the information on which decisions can be based.

Energy needs are determined by energy expenditure. Therefore, in principle, as was recognized in the report of the 1971 Committee (*1*), estimates of requirements should be based on measurements of energy expenditure. This kind of information is difficult to obtain, and sometimes the only feasible approach is to estimate requirements from measurements of intake. If people are, on average, in a steady state, with appropriate body composition and levels of activity, measurements of their mean habitual intake will provide an estimate of their mean expenditure. The intention of the word "habitual" is to even out short-term fluctuations in intake, but it is not possible to define it with precision.

As in all previous reports, the requirements derived in this report are intended to apply to people who are healthy, and in general the effects of disease should be considered separately. However, it is recognized that in many populations this condition is unrealistic. In children in particular, repeated infections are so common that the effects are discussed separately in section 9.

It cannot be assumed that observed levels of expenditure or intake always represent what is desirable for the maintenance of health. In developing countries actual intakes may be too low to allow for what was described in the report of the 1971 Committee (*1*) as "leisure time" activity. Again, in an affluent society some people may be less physically active than is thought desirable to ensure cardiovascular health. These are matters on which value judgements have to be made; in the opinion of the Consultation, estimates of energy requirement should allow for extra activities of this kind, as discussed in section 4.3.

4.2 Components of energy requirement

In the great majority of cases the largest component of energy expenditure is the basal metabolic rate (BMR), which can be measured with accuracy under standardized conditions. In this report, therefore, the principle of calculating all components of total energy expenditure as multiples of the BMR has been adopted.

It is recognized that this principle, used for the sake of simplicity, is likely to involve some inconsistencies. The relationship of the energy cost of a given level of physical activity to BMR will be affected by the nature of that activity, whether static or dynamic; by the body weight, because of the different values of BMR per kg at different body weights; and by age, because of age-related changes in body composition and BMR (*2–5*). As an example, values for the energy cost of walking are shown in Annex 3, expressed as multiples of BMR. For each of the rates of walking, the values for the two sexes, in two age ranges and with different body weights, do not differ by more than ±10% from the mean. On the other hand, Seliger et al. and Pařízková et al. show age to have more effect in younger subjects. The energy cost of a given activity, expressed as a multiple of BMR, was 45% greater in 35-year-old males than in children aged 12 years. It is clear that much more work is needed on the relative energy costs of different tasks in relation to age, sex, and body weight.

4.2.1 *Basal metabolic rate (BMR)*

In any individual the BMR is determined principally by body size, body composition, and age. The relationships are complex; the BMR per unit weight varies with age, being higher in children and lower in the elderly. The BMR per unit weight also varies with weight: within a given age range, BMR per kg is higher in short and light individuals and lower in tall and heavy ones.

For practical purposes the most useful index of BMR is the body weight. In the report of the 1971 Committee (*1*), a table of weights and associated BMRs was given, taken from a paper by Talbot, based on measurements on 2200 children. For the present report, a more extensive set of measurements was compiled from the literature; these are representative of BMR in developed countries and of some data from developing countries (*6*).[1]

The data base covers some 11 000 technically acceptable measurements on individuals of both sexes and all ages, who were considered to be healthy. It includes adults of different stature and of different weight for height, as well as individuals who fell within the designated range of "acceptable" weight for height. The data also include some children and adults who may have been on limited energy intakes before the BMR measurement. This may partly explain the lower BMRs in some groups.

A number of studies have attempted to assess the possibility of ethnic differences in BMR but these have failed to identify any differences

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[1] The figures in the tables of reference *6* differ slightly from those in the present report because additional data were included by the authors of that analysis after the present report was compiled.

that could not be related to the nutritional state or possibly to climatic conditions. Therefore, all studies have been incorporated into a single data base for developing the equations shown in later tables (Table 5 and Annex 1). In the opinion of the Consultation, these equations can be regarded as the best estimates at present available for predicting the BMR of healthy people in any population. They are, of course, no substitute for direct measurements when these can be made.

There are many ways in which equations can be developed for predicting the BMR from the collected data. Firstly, it was decided to formulate separate equations for each of the 6 age ranges defined in section 3.5.2.

Secondly, it was found that within each age range the most useful index of the BMR was body weight. The conventional use of surface area, or the inclusion of height, made no significant difference to the accuracy of prediction. Thirdly, many different types of equation were tested—linear, quadratic, logarithmic, etc. The more complex functions again added nothing to the accuracy of prediction. Therefore, for this report, in each age–sex group the BMR has been estimated from the body weight by the simple linear equations shown in Table 5 (see page 71). For the sake of completeness, equations have been derived for children below the age of 10 years, although in practice the BMR has not been used for estimating the energy requirements in this age group (section 6.3.1).

Equations that include height, and some examples of the effect of including it in calculations, are given in Annex 1. It is perhaps surprising that in most groups not only does height have no effect on improving the fit of the regression equations, but it also has little or no effect on the predicted value of the BMR independently of weight. This observation implies that for most age and sex groups the relationship between weight and height (body mass index; BMI) is not an important determinant of the BMR. For example, in a young adult male weighing 70 kg, the difference between the predicted BMR at a height of 1.6 m (BMI 27) and at 2 m (BMI 18) is less than 1%. Further examples are given in Annex 1. The effect of height is somewhat greater in adult women, and becomes significant in young children (0–3 years) and the elderly.

In adults and older children the calculation of the total energy requirement proceeds in two steps:

(*a*) The BMR per day is determined from the regression equations in Table 5 or from the tabulations in section 8, from either the actual or the desirable body weight (as discussed in section 3.5.1). If the energy need per kilogram is required, it can be derived by dividing the calculated BMR by the body weight used. It should be recognized that even at a fixed age, the BMR per unit body weight will not be constant for all weights. This is a major difference from the assumptions made by the 1971 Committee (*1*). The result will be a tendency to overestimate the energy needs of smaller people and underestimate for larger individuals.

(*b*) To obtain the total requirement, the estimate of BMR is multiplied by a factor that covers the energy cost of increased muscle tone, physical activity, the thermic effect of food, and, where relevant, the energy requirements for growth and lactation.

These factors are discussed in more detail below and evaluated in section 6. The approach is based on the recognition that a substantial proportion of total energy requirement is accounted for by the BMR, and that the cost of physical activity depends in part on body weight. Since the new equations for BMR indicate that the BMR per kg is higher in shorter and lighter individuals, the expression of physical activity in terms of BMR will increase the apparent cost of movement per kg for such individuals. Although there is little factual evidence for this, or for considering that the metabolic efficiency of physical activity correlates with metabolic efficiency under basal conditions, the present state of knowledge seems to justify the expression of activity as increments of BMR. As yet there is no convincing evidence that the total energy requirement of small children and small adults is the same per kg body weight as that of their taller and heavier counterparts, as was suggested by the 1971 Committee (*1*). The Consultation therefore adopted the present approach to maintain simplicity in calculating the energy requirements of individuals of different size.

Finally, it should be recognized that investigators may find the BMR of groups in their country differs from that predicted by the present general equations. This is to be expected, since in the data used for developing the current equations Indian subjects were found to have BMRs approximately 10% below the average and northern Europeans and North Americans tended to have higher values at equivalent age, height, and weight for height. These observations are not in themselves evidence for ethnic differences in BMR, so for the present the general equations have been maintained for all groups.

4.2.2 *Growth*

The energy cost of growth includes two components: the energy value of the tissue or product formed and the energy cost of synthesizing it. The total cost will therefore depend upon the composition of the product. The energy value is the heat of combustion, without the deductions for losses in urine and faeces which are allowed for by the Atwater factors. The average values for protein, fat, and carbohydrate are 5.7, 9.3, and 4.3 $kcal_{th}$ (24, 39, and 18 kJ) per g. Numerous estimates of the costs of synthesizing protein and fat have been derived from work on animals (*7, 8*). The cost for protein is greater than for fat, even when fat is being synthesized from carbohydrate precursors. Except in the case of young infants and during lactation, the estimates of energy cost are not very critical, since human growth is a slow process, taking up a small proportion of the energy requirement. Moreover, since the composition of the tissue formed cannot be known accurately, and even the composition of breast milk is somewhat variable, it is only possible to make approximate estimates of the energy cost of growth.

In young children a rounded-off value of 5 $kcal_{th}$ (21 kJ) per g for the energy cost of growth has been widely accepted (*9*). Annex 4 summarizes information on which this estimate is based. Since in this report the energy requirements of children up to 10 years are estimated from intakes (section 6.3.1), a factor for the energy cost of growth has been used only in deriving the requirements of adolescents (Annex 7). In theory a single factor is not appropriate because of variations in body composition at this stage of life (section 3.4). However, during the pubertal spurt the growth component still represents a very small fraction of the total energy requirement. In contrast, the cost of growth becomes very important in any consideration of the requirements for catch-up growth in malnourished children (section 9).

In adults a higher figure is obtained for the energy cost of weight gain under different conditions (Annex 4). This may be because relatively more fat is being laid down.

The extra energy requirements for pregnancy and lactation are discussed in detail in section 6.2. The energy stored during pregnancy includes the energy laid down in the fetus, placenta, and uterus as well as the additional protein and fat stored in the mother. The composition of the tissue laid down varies at different stages of pregnancy, but since the overall extra cost is only some 10% of the total energy requirement, detailed computations, appropriate to the different stages of pregnancy, are not justified.

The energy requirement of the lactating woman must include the energy lost in milk. The daily amount should be taken as that produced by healthy well-nourished mothers (section 6.2). An additional allowance has to be made for the energy cost of producing the milk. As in the report of the 1971 Committee (*1*), the efficiency of conversion of food energy to milk energy has been taken as 80% (*10*).

In many societies women do not consume the extra amounts that seem to be needed to meet the energy requirements of pregnancy and lactation, and it has been suggested that there may be metabolic adaptations leading to increased efficiency (section 4.7). At present, however, there is no well documented evidence for this and further research is needed.

4.2.3 *Physical activity*

The level of physical activity must obviously be considered in detail when assessing energy needs. Some activities are essential for the individual and the community, and can be considered as economic activities which are life-sustaining. These are designated as *occupational* energy needs. Previous reports have given general estimates of the energy costs of light, moderate, and heavy activity. The difficulty of applying such figures in practice is recognized, since in many cases activity varies from day to day and from season to season.

The 1971 Committee (*1*) included an allowance for "leisure-time" activities. The present Consultation attaches much importance to such activities, which are perhaps more appropriately termed *discretional,* as they are considered desirable for the wellbeing of the community and the health of the individual and the population.

Because of the wide range of variation in both occupational and discretionary activities, it is only possible to give examples typical of particular groups. The examples worked out in section 6 are designed to serve as patterns, showing the method by which the energy needs may be calculated for any particular situation. The notes that follow provide some guidelines for the application of this approach.

(1) *Occupational activities.* The traditional classification of work according to occupation is maintained in this report, but care must

be taken to ensure that there is an adequate description of the occupation. For example, farmers in affluent societies may be relatively sedentary compared with farmers in developing countries who are involved in very strenuous manual labour. The energy cost of travelling or walking to work should be considered as part of the essential energy needs. It must also be recognized that older children and women in developing countries commonly play a significant role in agriculture, in caring for livestock, and in looking after younger children. This is an important contribution to the economy and viability of the household, and energy should be allowed for these essential tasks.

(2) *Discretionary activities.* There may be many benefits to societies from additional activities outside working hours. The requirement to cover them should not be considered as dispensable, since it usually contributes to the physical and intellectual wellbeing of the individual, household, or group. Such activities can be divided into three categories:

(*a*) *Optional household tasks.* A number of optional tasks, such as working in the garden or repairing and improving the home, are an important part of family life. In estimating requirements, an energy allowance should therefore be made for adults for all these activities.

(*b*) *Socially desirable activities.* A variety of socially constructive tasks, for example attending community meetings, games or festivals, or walking to health clinics or places of worship, require additional energy expenditure. In some developing countries, where people's main occupation involves a large expenditure of energy, there may be limits on the ability of members of the community to respond to a demand for activities of this kind. For children, additional energy is important as part of the normal process of development, for activities such as exploration of the surroundings, learning, and behavioural adjustments to other children and adults.

(*c*) *Activity for physical fitness and the promotion of health.* At all ages physical fitness and wellbeing may depend on leisure-time exercise, and an allowance should be made for this even if it is recognized that at present many people in affluent societies do not expend enough energy in this way. Rather than reducing the estimate of energy requirement, it should be maintained to allow such people to become more physically active. It is, however, impossible to state precisely the desirable level and duration of extra activity.

In sedentary workers, cardiovascular responses to exercise are often inappropriate and muscular strength is limited (*11, 12*). A small allowance for short periods of physical exercise at a relatively high rate would therefore be beneficial. Although not all authorities are agreed, there is in our view good evidence that for middle-aged men short regular periods of physical exercise at a relatively high rate may have a beneficial effect on cardiovascular risk (*13, 14*).

4.2.4 *Metabolic response to food*

The increased oxygen uptake (so-called "specific dynamic action") after a meal depends on the nutrient composition of the food consumed, and the amount of energy ingested. The greater the energy demands of a subject, because of his size or physical activity for example, the greater the absolute rate of energy expenditure in digesting, absorbing, and storing the larger amounts of ingested nutrients. However, the measurement of the energy cost of these processes in the individual is not easy. It is difficult to separate the energy expended in excess of the basal rate after eating a meal, from the energy cost of the physical activity involved in sitting, eating, and digesting.

For the purpose of estimating energy expenditure, the practical solution is to measure the metabolic rate of individuals in the post-prandial state without limiting minor physical movement. The rate obtained in this way represents the resting metabolic rate. It is greater than the BMR because it includes the energy cost of metabolizing and digesting a meal, as well as the cost of increased muscle tone and minor physical activity. By combining the results of measurements made in the morning, afternoon, and evening, an average figure can be obtained which is an estimate of the resting metabolic rate.

4.3 Changes in energy requirements with age

The most important component of energy expenditure, the basal metabolic rate, depends on the mass of metabolically active tissue in the body, the proportion of each tissue in the body, and the contribution of each tissue to the energy metabolism of the whole body. The changes in body composition with age, discussed in section 3.3, markedly affect energy requirements, since some organs of the body are much more metabolically active than others. Table 1

Table 1. Metabolic rates (MR) of organs and tissues in man

Organ	Adult			Neonate		
	Weight[a] (kg)	MR/day kcal$_{th}$ (kJ)	% of whole-body MR	Weight (kg)	MR/day[b] kcal$_{th}$ (kJ)	% of whole-body MR
Liver	1.6	482 (2 017)	27	0.14	42 (176)	20
Brain	1.4	338 (1 414)	19	0.35	84 (352)	44
Heart	0.32	122 (510)	7	0.02	8 (33)	4
Kidney	0.29	187 (782)	10	0.024	15 (63)	7
Muscle	30.00	324 (1 356)	18	0.8	9 (38)	5
Miscellaneous, by difference			19			20
Total	70.00	1 800 (7 530)		3.5	197 (824)	

[a] Organ weights taken from Boyd (*15*).

[b] Metabolic rates for the neonate estimated by assuming that the metabolic rate of each organ per unit weight is the same as in the adult. The total activities of the tissues listed are expressed as fractions of the total basal energy expenditure in the adult and the neonate. The total basal metabolic rate in the neonate approximates to that measured by Benedict & Talbot (*16*).

shows that, in the neonate the brain comprises about 10% of the total body weight and may account for 44% of the total energy needs of the child under basal conditions. On the other hand, the energy needs for muscle metabolism at this time are very low because of the relatively small muscle mass. Table 1 also shows that the liver is much more metabolically active than muscle, so that when the mass of muscle is reduced in the aging adult, the whole-body metabolic rate relative to lean tissue mass will also alter. These changes in body composition in children and adults have to be taken into account when calculating the energy requirements of a particular section of the population.

There are also altered activity patterns with age; children become progressively more active once they are able to crawl or walk and the physical activity patterns of adults are usually dominated by the nature of their work. If adults retire from work, this change in habits must be recognized in estimating their energy requirements, but it should not be assumed that the marked decline in activity that often occurs in the elderly is either inevitable or desirable. If energy intake declines with increasing inactivity, then an individual is much more likely to have a diet deficient in one of the essential nutrients. In determining the desirable minimum activities the Consultation suggests that the energy allowance considered appropriate for discretionary activities should be maintained throughout adult life and increased for those who have retired from work.

4.4 Sex differences in energy requirements

The basal energy expenditure on a weight basis differs little between pre-adolescent boys and girls, but since there are differences in body weight and composition from the first few months of life, and different physical demands are made on boys and girls, their energy requirements are considered separately.

After maturity, men have a relatively greater muscle mass than women, which would tend to reduce their BMR when expressed in terms of lean body mass, since muscle has a low metabolic rate (Table 1). However, the greater body fat content of women means that the observed BMR per unit total body weight is somewhat lower in women.

The energy demand for physical activity will often depend on the different types of employment for men and women. However, the heavy burden of agricultural work for women in rural communities must be taken into account. In addition, this report suggests that for both sexes there should be a minimum desirable energy requirement to allow the same amount of discretionary activity.

4.5 Variability in energy expenditure

In any assessment of the average requirement, both intra- and inter-individual variability must be recognized. The former results from short-term fluctuations in energy intake and expenditure. In the United Kingdom it has been found that measurements over a period of 2–3 weeks were needed in order to assess correctly the intakes of individuals (*17*). There are also short-term fluctuations in energy output, and it has been found that even under well controlled conditions, observations may have to be continued for several weeks before input and expenditure are balanced (*18*).

It is also generally recognized that in a group of apparently comparable people there is much inter-individual variation in habitual energy expenditure, and hence in requirement. In a number of selected studies, the measurement of total energy expenditure over a week indicates that the inter-individual variability of expenditure, in a specified group, has a coefficient of variation (CV) of about ±12.5% on a body-weight basis (*19*).

There is almost no information about the intra-individual variation in energy requirements in developing countries. Unpublished data from Papua New Guinea indicate a coefficient of variation of 10–16%.

4.6 Measurement of energy expenditure

4.6.1 *Basal metabolic rate (BMR)*

The data for BMR are extensive and the equations in Table 5 (see page 71) allow reasonably precise estimates for individuals of a given sex and weight. Direct measurement of the BMR demands close attention to detail and imposes artificial conditions on the subject —who should be in the post-absorptive state and at complete rest in a thermoneutral environment. In practice the BMR measured in this way is approximately equal to the energy expenditure of subjects during sleep. It is therefore considered valid to measure the BMR of individuals and to assign this energy cost to the time during which the subject is asleep. Anxiety is often cited as an important cause of increased energy expenditure, but direct estimates do not confirm this (*20, 21*).

4.6.2 *Physical activity*

The different types of activity undertaken by an individual can be identified and the time spent in each activity measured. The energy cost of each activity can then be obtained by measuring the subject's oxygen uptake while performing the task, either with a Douglas bag to collect the expired air or a less restricting spirometer such as the Kofranyi-Michaelis apparatus. Since there are no studies on the energy expenditure of free-living subjects that do not rely, directly or indirectly, on such encumbering apparatus, it is not possible to say whether the use of respirometry introduces errors. Numerous studies of the energy cost of different activities have been made by this procedure (*22, 23*). It does not give the net energy cost of each activity above the BMR, but monitors the total rate of energy expended during the period of exercise. The values tabulated in Annex 5 are used in section 6 to produce approximate estimates of the energy expenditure of individuals under different conditions.

The energy cost is usually expressed per minute rather than per day. The total for 24 hours is then calculated according to the time spent on that activity. The energy cost of a standardized form of physical activity is relatively easy to measure, and it is also possible to estimate the variability in energy cost between individuals in performing the same task. It is much more difficult, however, to obtain accurate values for those tasks that combine a variety of movements, some of which demand the use of heavy parts of the body while others involve only small muscle groups without major weight-bearing or movement of the body.

It is also difficult to generalize on the extent to which differences in body weight affect the energy expenditure for a given type of physical activity (see section 4.2 and Annex 3). A relation between energy cost and body weight is to be expected when the task involves moving the body, but not when it involves work on external objects. Clearly, many tasks will be a mixture of both types. In the absence of data it has been assumed in this report that, regardless of body weight, the same multiple of BMR can be used to express the energy cost of each activity. It is clearly desirable that, wherever possible, investigators should make their own measurements.

A number of workers have estimated the energy expenditure of free-living subjects over periods of several days by monitoring and integrating the number of heartbeats (*24–26*). This procedure relies on indirect calorimetry, since for each individual a calibration curve has to be made relating heart rate to oxygen uptake. The main drawback of this method is that at low levels of activity many physiological and psychological factors may affect the heart rate without appreciably affecting energy expenditure.

4.6.3 *Time-scale of estimates*

For practical purposes the requirement is generally expressed as a daily rate, although the estimates refer to levels of *habitual* energy expenditure. It is recognized that expenditure varies not only from day to day, but also from week to week. The estimates should represent the average requirement over longer periods. The variability in energy requirements within a group can then be attributed to inter-individual variation only and not to intra-individual variation.

The length of the period chosen will vary with the circumstances. It is well known that there can be substantial variations in the energy requirements of the same subject under different circumstances; for example, the demand for physical activity increases during harvesting in developing countries. At this time of the year energy expenditure may exceed intake and, if so, body weight falls. While some weight loss may be tolerated for a short time, it may be necessary to take account of intermittent periods of heavy work in calculating overall energy needs.

4.6.4 *Corrections for metabolizable energy*

Once the requirements for energy are obtained from measurements of energy expenditure, the dietary intake needed to meet the energy demand must be determined. Intakes of metabolizable energy have to be calculated to allow for the availability of dietary energy from different sources which may present special problems in some cases, for example a diet rich in fibre (see section 7). The traditional Atwater factors were designed to allow for non-available energy in different foods, but the corrections for unabsorbed carbohydrate are made in different ways in different food tables (see section 7.1). In general, the Atwater factors are still the most suitable in the absence of more specific knowledge on the availability of energy in particular foods.

When intakes are being compared with requirements, it is usually preferable to correct for the metabolizable energy of the diet rather than to adjust the estimate of requirement. For example, if a diet provides only 90% of the metabolizable energy predicted from the Atwater factors, for most purposes it is more convenient to correct the estimated energy intake by a 10% reduction, rather than to increase the requirement by 10%. However, for some uses the latter method may be more appropriate.

4.7 Adaptation in energy requirements

The general principles of adaptation have been considered in section 3.1. Adaptation to changes in energy intake can affect energy requirements in three ways; by alterations in body size (already discussed in section 3), by metabolic adaptation, and by behavioural adaptation.

4.7.1 *Metabolic adaptation*

A very substantial adaptation in total energy requirements can occur on submaintenance intakes, but this involves large changes in most if not all of the factors contributing to total energy expenditure. In the classical Minnesota study of Keys et al. (*27*) normally nourished subjects were able to achieve approximate energy balance after 6 months on half their usual energy intake. There was, however, a profound fall in body weight (part of which was lean tissue), a reduction in physical activity, and some mental changes, as well as metabolic adaptation shown by a fall in the basal metabolic rate. This degree of adaptation was clearly disadvantageous and the problem is to define the range of adaptation in total energy expenditure that can be achieved without any detectable disadvantage.

When there is a substantial fall in energy intake, in addition to the loss of body weight there is a reduction in the BMR, which declines over a 3-week period by up to 15% when expressed per unit of body weight (*27*). Thereafter, further falls in BMR are achieved primarily by a progressive loss of active tissue mass. It is uncertain whether this degree of metabolic adaptation can occur in the absence of a reduction in body size, nor is it clear whether, under conditions of slight energy restriction, there is a fall in the BMR which can then be maintained to bring the body back into energy balance. Table 2 shows data on the response to semi-starvation in volunteers, compared with the energy expenditure of men and women in Papua New Guinea (*28*). Results from a group of well-fed British women studied by similar methods are also given to show that the resting metabolic rates, which include the metabolic response to food, are similar in the different ethnic groups. From these data the major differences in energy turnover appear to relate to the energy available for physical activity. However, subtraction of the resting metabolic rate rather than the BMR from total expenditure will tend to underestimate the expenditure on physical activity.

When subjects of normal weight are overfed experimentally there is an increase in both lean tissue and body fat, but some metabolic adaptation can also occur. Many overfeeding experiments have been undertaken, but there is little information on total energy expenditure under these conditions. Short-term overfeeding studies have generally shown that most of the extra energy is stored and not dissipated as heat (*29, 30*). However, it has been repeatedly confirmed that there are modest increases in the BMR with substantial overfeeding (*31*). Long-term overfeeding experiments have been claimed to demonstrate remarkable changes in the body's

Table 2. Examples of energy expenditure in semi-starved and undernourished subjects

Nutritional status	USA men (27)		Papua New Guinea (Kaul) (28)		British women[a]
	Normal	Semi-starved	"Undernourished"		Normal
			Men	Women	
Body weight (kg)	70	53.2	56.3	48.1	55.1
Fat-free mass (kg)	60.1	49.9	50.7	37.5	37.8
Daily energy output					
(kcal$_{th}$/day)	3 468	1 570	2 347	1 831	2 125
(MJ/day)	14.51	6.57	9.82	7.66	8.89
Basal metabolic rate					
(kcal$_{th}$/day)	1 595	964	–	–	1 178
(MJ/day)	6.67	4.03	–	–	4.93
Resting metabolic rate					
(kcal$_{th}$/day)	–	–	1 646	1 563	1 525
(MJ/day)	–	–	6.89	6.54	6.38
Metabolic rate—basal or resting per kg fat-free mass					
(kcal$_{th}$/day)	27	19	32	42	40
(kJ/day)	113[c]	80[c]	134[d]	176[d]	167[d]
Estimated physical activity[b]					
(kcal$_{th}$/day)	1 613	488	466	268	600
(MJ/day)	6.75	2.04	1.95	1.12	2.51

[a] Unpublished data of James et al.

[b] Physical activity estimated in the USA men by subtracting the basal metabolic rate plus a theoretical 10% of intake as specific dynamic action from the total output. For the Kaul group and the British women the resting metabolic rate, which includes the specific dynamic action, has been subtracted from total energy output.

[c] Basal metabolic rate.

[d] Resting metabolic rate.

ability to cope with overfeeding (*32*). Unfortunately these studies did not include direct measurements of energy expenditure.

Metabolic adaptations in other components of energy expenditure have been sought under conditions of underfeeding and overfeeding. It has been suggested that there is an interaction between the metabolic response to food and exercise (*33*). This response may increase with overfeeding and decline during semi-starvation, though the effect is small. There is little evidence that exercise performed under fasting conditions in semi-starved or overfed individuals is appreciably different in efficiency. Finally, studies on the specific dynamic action of a standard meal without exercise in semi-starved or overfed individuals do not suggest major changes in their metabolic response, although in children recovering rapidly from malnutrition the metabolism surges after a meal (*34*), and this is related to their rate of growth.

The documented changes in metabolism when energy intake is altered suggest, therefore, that with the present state of knowledge the range of metabolic adaptation must be considered to be small. A variety of mechanisms have been suggested to explain such differences as have been found in the efficiency of energy utilization, including changes in plasma thyroxine and tri-iodothyronine concentrations and in the processes of protein turnover, substrate cycling, and perhaps activation of brown adipose tissue metabolism. Evidence on the quantitative importance of each of these factors is scanty.

4.7.2 *Behavioural adaptation*

A marked reduction in food intake leads to a profound decrease in physical activity (*35*). Children in Guatemala were found to decrease their energy expenditure without changing their growth rate when their dietary energy was reduced by 10% (*36*). On the other hand, in studies in Mexico, supplementation of the diet of children led to an increase in physical activity and exploratory behaviour (*37*). It has also been shown (*38*) that when the diet of male agricultural workers in Guatemala was supplemented with additional food, there were appreciable increases in their activity at work and in their discretionary activity without any increase in body weight. There was also an improvement in their sense of wellbeing. These findings suggest that limited food intake makes an appreciable difference to the work capacity of a community and that this happens without, in general, alterations in body weight. Similar improvements in subjective wellbeing with very small weight increases have been found in lactating Gambian women when given supplementary food (*39*).

This relationship between energy intake and work output deserves serious consideration during the assessment of energy requirements. The need to provide for the energy cost of socially desirable activity in the home and community has already been emphasized.

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5. PRINCIPLES OF ESTIMATING PROTEIN REQUIREMENTS

5.1 The metabolic background

Even in the steady state, body proteins constantly undergo breakdown and resynthesis. When growth is occurring, not only is there a net deposition of protein, but the rates of both synthesis and breakdown are increased (*1–3*). The principles underlying this process of protein turnover have been described in detail elsewhere (*4*).

The rates of turnover vary from tissue to tissue, and the relative contributions of different tissues to total protein turnover change with age and adaptation to various levels of protein intake (*4–7*). The amino acids released by breakdown are reused for protein synthesis. However, because this process of reutilization is not completely efficient, some amino acids being lost by oxidative catabolism, both essential amino acids and a dietary source of nitrogen are needed. The daily turnover of body proteins is, in fact, several-fold greater than the amino acid intake, showing that the reutilization of amino acids is a major contributory factor to the economy of protein metabolism (*4, 5*).

This process of recycling, which includes interchange of amino acids between tissues as well as intracellular reutilization, depends on various metabolic and hormonal factors and is influenced by the physiological status of the host. Thus, reutilization of amino acids is highly efficient during rapid catch-up growth and in convalescence from a catabolic episode resulting from injury or infection (*4*). The increased efficiency of reutilization under these circumstances results in the improved use of dietary amino acids, giving the dietary protein an apparently improved biological value (*8*).

This principle extends to the adaptation of protein metabolism under circumstances of restriction or excess of dietary protein or amino acid supply. Adaptation to a submaintenance level of protein intake leads to a diminished turnover of tissue protein and a reduced rate of catabolism of the amino acids liberated by protein breakdown (*9, 10*). In this way, within limits, the tissue protein pool can reach a new steady state appropriate to the diminished intake of protein.

Under the experimental conditions of a protein-free diet, protein synthesis and breakdown continue via the reutilization of amino acids. This process becomes very efficient, but a small proportion of amino acids are still catabolized to urinary nitrogenous compounds and there is some nitrogen loss in the faeces. These represent what has been called the obligatory loss (*11–13*). The extent of this loss and its various components is discussed in section 5.5.

It has become clear since the 1971 Committee's report (*12*) that a key question in relation to the assessment of protein requirements is the extent to which people living on low protein intakes can adapt by increasing the efficiency of recycling and reducing the extent to which amino acids "escape" from the system and are catabolized. One objective, therefore, in determining protein requirements is to define the point at which adaptation is exceeded; beyond this point there will be progressive loss of body protein and deterioration of tissue function.

5.2 Adaptation to low protein intakes

As has been fully discussed in previous reports, the protein requirement has two components—that for total nitrogen and that for essential amino acids—so that a diet may be deficient in quantity or quality of protein. Both aspects may, in theory, be affected by adaptive processes, but almost nothing is known about adaptation of essential amino acid requirements.

All healthy individuals are able to adjust total nitrogen (N) excretion to balance their intake over a certain range. For a time, as the lower limit of this range is approached, body N loss exceeds N intake, and there is a reduction in the mass of body protein leading to a new steady state. This is clearly a form of adaptation. At even lower intakes the limits of adaptation are exceeded, and there will be a continued depletion of body protein resulting ultimately in death. Two questions have to be considered:

(*a*) First, in passing from one steady state to another there is a loss of body protein; is this of any functional significance? When an adult man is transferred from a higher than customary N intake to one that is close to the physiological minimum, e.g., from 14 to 4 g N per day, a level of excretion close to a new steady state is reached in about 7 days (*14*), and over this period there is a cumulative N loss equivalent to about 1.5% of total body N. In similar studies on children the new steady state was reached more rapidly, with a total loss estimated at 1% of body N (*15*). In experimental animals the losses on passing from a customary to a lower protein intake are relatively greater. From such experiments it is known that initially most of the N is lost preferentially from the liver and gut (*16, 17*). Later, because of the recycling discussed above, it is the N content of muscle and skin that is mainly reduced (*18*).

It seems doubtful whether a loss of 1–2% of body N in man could represent a significant degree of depletion rather than adaptation. Experimentally, the capacity of animals maintained on low protein intakes to respond to stresses of various kinds does not seem to be impaired (*19*), except for an increase in perinatal mortality (*20*). Systematic evidence on this question is not available in man, except in children who are demonstrably malnourished (*21*), because of the difficulty in matching compounding variables other than nutritional state. Nevertheless, it is not justifiable, given the present state of knowledge, to assert that there are no functional differences between steady states at lower and higher protein intakes. For example, albumin synthesis and breakdown rates, albumin pool size, and perhaps plasma concentration, are somewhat lower at low intakes (*22, 23*).

(*b*) The second question is whether, on a habitually low protein intake, it is possible to reduce the lower limit of the range of protein intake at which N equilibrium can normally be maintained. Obligatory urinary N losses in subjects in different countries, presumably with different habitual protein intakes, are remarkably uniform (Table 3). Thus, the way to reduce the minimum requirement for nitrogen balance is probably to increase the efficiency of utilization of amino acids, i.e., an increase in the recapture of amino acids for protein synthesis, as discussed above, and a decrease in amino acid oxidation.

In some of the long-term balances summarized in section 6 (Table 17), in which protein was fed at about the same level as the estimated requirement, some subjects showed a trend towards a lower urinary N output at a fixed intake, but in others there were no such trends. Moreover, in spite of an earlier observation (*38*) that Nigerian farmers could achieve balance with an intake that was apparently inadequate for North American men, several short-term balances that have been carried out since 1971 reveal no striking differences in the estimates of maintenance requirement in relation to body cell mass obtained in studies of well-nourished subjects in different countries. However, the question of long-term adaptation cannot be answered definitively without further research.

Although it has been shown in both animals and man (*39, 40*) that enzymes of amino acid metabolism adapt to changing levels of protein intake, there is no evidence that their activity can be reduced to zero, allowing for 100% reutilization of amino acids. It is possible that some essential amino acids may be more efficiently conserved than others (e.g., lysine). From these considerations it is evident that at the maintenance level the limiting amino acid will be the one that is least efficiently conserved.

The question has been raised as to how far recycling of urea through the gut could contribute to amino acid economy. The ammonia liberated by hydrolysis in the colon is available for the formation of nonessential amino acids (*41*). However, this process cannot result in any *net* increase in protein synthesis unless there is a parallel increase in the availability of the essential amino acids or their carbon skeletons—a situation that is unlikely to exist under natural conditions (*42*).

Given the evidence currently available, it must be concluded that there is probably only limited scope for metabolic adaptation to N

Table 3. Obligatory nitrogen losses

Subjects and country	Reference	No. of subjects	Age	Body weight (kg)	BMR/kg (kcal_{th})	BMR/kg (kJ)	Excretion (mg N/kg) Urine	Excretion (mg N/kg) Faeces	Excretion (mg N/kg) Total[a]	Total N (mg/kcal_{th})	Total N (mg/kJ)
Infants and children											
	(24)	7 (f)	4– 6 months	7.3[b]	54	226[d]	37	20	67	1.24	0.30
	(25)	11 (m)	9–15 months	10.2[b]	56	234[d]	54	22	86	1.54	0.37
	(26)	5 (m)	17–31 months	12.6[b]	57	238[d]	34	20	64	1.12	0.27
Young adults											
Women											
USA	*(27)*	20	23 years	59	23	96[d]	25	8	41	1.78	0.42
	(28)	11	22 years	60	23	96[d]	31	8	47	2.04	0.49
Men											
USA	*(29)*	13	20 years	71	26	109	38	14	60	2.31	0.55
USA	*(30)*	83	21 years	73.5	21	88	37	9	54	2.57	0.61
China (Province of Taiwan)	*(31)*	50	23 years	55	26	109	33	13	54	2.08	0.50
India	*(32)*	4	27 years	46	27	113	38	23	69	2.56	0.61
Nigeria	*(33)*	9	26 years	54	26	109	34	23	65	2.56	0.60
Japan	*(34)*	9		63	26	109[d]	33	13	54	2.08	0.50
Elderly persons											
Women											
USA	*(35)*	11	77 years	63.5	17	71	24	10	42	2.47	0.59
Men											
USA	*(36)*	6	68 years	83[c]	19	79	27	10	45	2.37	0.57
USA	*(37)*	8	70 years	71.6	22	92	34	12	54	2.45	0.59

[a] After the addition of 10 mg or 8 mg N/kg for skin and miscellaneous losses, in children and adults respectively. Previous reports used a figure of 5 mg N/kg.

[b] Assumed median weight (NCHS) at mid-point of age range.

[c] Body weights were 8–19 kg above the expected weight for height.

[d] BMRs estimated from equations in Table 5. Others were measured by the investigators.

intakes below the physiological minimum for N balance found in subjects with "normal" intakes. The important question that remains is whether the degree of adaptation that does occur, consistent with the maintenance of nitrogen equilibrium, represents a metabolic adjustment without functional significance, or whether it is detrimental to health and long-term survival. The answers to these questions will obviously influence the nutrition of populations subsisting on diets providing low levels of protein. They are also relevant to the determination of protein requirements in healthy, well-nourished individuals.

At the other end of the scale, it is necessary to define the limits of successful adaptation to high protein intakes. As pointed out in section 3.1, it would not be justified to assume that high intakes are automatically optimal. It is known that excessive protein intakes are accompanied by modest elevations in blood urea nitrogen (*43*), which facilitates urea excretion, and by an increase in urinary calcium content (*44, 45*). Low-birth-weight infants fed very high levels of protein (5–6 g/kg per day) have in some instances experienced a reduction in growth rate, urine abnormalities, lethargy, and fever (*46, 47*), and some studies suggest an impairment in neurological development (*48*).

5.3 Relationships between energy and protein requirements

The processes of protein synthesis and possibly of breakdown (turnover) require sources of dietary energy and are thus sensitive to energy deprivation. Consequently, the energy balance of the body becomes an important factor in determining nitrogen balance and influences the utilization of dietary protein.

The magnitude of the basal energy needs and of the total amount of protein turned over in a day are both related to active tissue mass (*4, 49, 50*). Moreover, in young animals and growing children both rates per unit of active mass are increased compared with those observed in adults (*51*). Nevertheless, as discussed in the next section, it has not proved possible to establish a constant numerical relationship, covering all age ranges, between BMR and either protein requirement or obligatory nitrogen loss, although such a relationship has been assumed by previous committees (*11, 12*).

There are, however, other ways in which the interactions between energy and protein metabolism are important in relation to protein requirements. It has been known for some time that the utilization of dietary protein is influenced by energy intake and notably by energy balance (*13, 52–54*). It has been demonstrated (*54–57*) that, at any given level of dietary protein, addition of energy improves N balance until the response reaches a plateau, which represents the limitations imposed by the dietary protein level. This effect of energy balance can be extended further by raising the protein intake. Studies on animals (*13*) and on man (*58*) suggest that increasing the plane of energy intake enhances protein synthesis and reduces amino acid oxidation.

The influence of energy balance on N balance extends from suboptimal up to excess levels of energy intake, so that any change in energy intake above or below the subject's needs is likely to influence his N balance, the effect being of the order of 1–2 mg of N retained per kcal_{th} added (0.24–0.48 mg of N per kJ) (*59, 60*). This has important implications for the determination of protein requirements when N balance is used as the criterion of adequacy (*59–61*). In view of the difficulty of determining the energy needs of individual experimental subjects, this effect of energy intake must be carefully considered when assessing estimates of protein requirements obtained by the N-balance method.

A less well defined relationship appears to exist between protein intake and the efficiency of utilization of dietary energy. A limited number of studies (*60, 62*) suggest that changes in intake or utilization of protein produce changes in the rates of weight gain of children and adults under isoenergetic conditions of intake and expenditure. This may be an aspect of the general principle that the improvement in N balance caused by adding energy to the diet can be inhibited when the protein content of the diet is too low (*52, 53*).

5.4 Requirements for total nitrogen

In previous reports (*11, 12*) a factorial method was used as the basis for predicting the protein requirements of various age groups. This method involved measuring obligatory nitrogen losses (i.e., the amount of nitrogen present in urine, faeces, sweat, etc.) when the diet consumed contained no protein but was otherwise adequate. The requirement for dietary protein was considered to be the amount needed to replace this loss, after adjustments for the inefficiency of dietary protein utilization and the quality of the dietary protein based on its amino acid pattern. For children and pregnant and lactating women, an additional amount of protein (required to support tissue growth and milk formation) was incorporated into this factorial estimate of requirements.

The method adopted by the 1971 Committee (*12*) has not always been clearly understood. It may be useful to retrace the steps of that Committee's argument and to fill in some gaps where the basis on which estimates were determined is not entirely clear.

Direct measurements on young adult males show that the sum of obligatory losses in urine and faeces is approximately 49 mg of nitrogen per kg of body weight. This figure was derived from the literature and from other studies (*30, 63–65*) available to the Committee, which had not been published at the time it met. To this figure was added 5 mg of N/kg to allow for miscellaneous unmeasured losses (sweat, etc.). In order to extrapolate these data to other age and sex groups for which direct results were not available, the Committee, following the example of its predecessor (*11*), made use of the general relationship that has been observed in animals of different species between obligatory or endogenous nitrogen loss and basal metabolic rate (BMR) (*66*).

The BMR of adult males was estimated as 25–27 $kcal_{th}$/kg per day (105–113 kJ/kg per day), so that the obligatory loss was taken as approximately 2 mg of N/basal $kcal_{th}$ (0.48 mg of N/basal kJ). The Committee used this value to estimate the obligatory losses in other groups. Thus, for adult women, the estimate of obligatory loss was reduced by about 10% on the basis of the known sex differences in the BMR of adults. In children and adolescents the obligatory loss was calculated from the figures for BMR given in Annex 4 of the Committee's report (*12*). These BMR figures related to children of reference weight for age and height up to the age of 18 years, and were not used for estimating the BMR in adults. The Committee recommended that, after the BMR had been determined for any age and sex group, further adjustments within the group should be related to body weight.

Since 1971 additional studies have been published on obligatory losses in 2-year-old children, young men, and elderly men and women. There is no further information about losses in older children and adolescents. The results of these studies are summarized in Table 3.

The agreement among the values for urinary loss per kg of adult body weight is remarkable, particularly when one considers the difficulty in defining the exact period of time needed for the urinary loss to reach a stable level. The length of the study will probably have less effect on the faecal loss, yet it is the faecal loss that is more variable. It was higher in Indians and Nigerians, presumably because of the nature of their diet.

From evidence available to the 1971 Committee it was apparent that the ratio of obligatory losses to BMR might be significantly less in infants and young children than in adults. The new data from preschool children confirm this difference.

The 1971 Committee was the first to consider the important question of whether the obligatory nitrogen loss can be used to predict the amount of dietary protein needed to meet the minimum physiological requirement. Minimal protein needs had previously (*11*) been expressed in terms of a hypothetical reference protein that could be used with 100% efficiency; i.e., when fed at the level of the obligatory nitrogen excretion there would be no increase in the urinary and faecal nitrogen losses in excess of those found on a protein-free diet. An ideal amino acid pattern was proposed for the hypothetical reference protein that would provide a standard for determining the quality or number of other proteins.

The 1971 Committee examined the results of balance studies in which egg and milk proteins had been fed to infants, children, and adults at levels below or close to the requirement. This was defined as the amount needed to achieve nitrogen balance in adults and adequate retention in children. It was evident that even these high-quality proteins were not utilized with the efficiency previously assumed, on the basis of animal studies and a few studies in man which had involved very low protein intakes. To meet the minimum requirement, the dietary intake of various age groups had to be 25–50% above that expected from the obligatory losses plus a growth increment. It was proposed that the average requirement for egg and milk protein should be taken as 30% greater than that given by the factorial method for all ages. Re-examination of the data now suggests that the addition should have been of the order of 45%.

The present Consultation has adopted a modified approach, based on that of its predecessor. It was useful to establish the constancy of the obligatory loss, as shown in Table 3. However, once it became clear that N balance could not be achieved simply by replacing the obligatory loss, even with the best quality proteins, the magnitude of that loss becomes of little relevance. The important variable is the efficiency of utilization of dietary protein at the maintenance level. The starting point in determining the present estimates is therefore the direct measurement of the N needed for zero balance in short-term or long-term studies.

Most of the nitrogen balance studies that have been made in recent years have been either on young adult men or on young children. These provide two relatively fixed points, so that the protein requirements of other age groups can be obtained by interpolation, with an allowance, where appropriate, for the growth increment. As discussed in section 6.3, the BMR was not found to be a satisfactory basis for estimating either the total protein requirement or the maintenance requirement.

Since all the estimates of protein requirements are obtained either directly or indirectly from measurements of N balance, the limitations of balance studies need to be considered in some detail.

5.5 Principles of nitrogen balance

The nitrogen-balance technique involves the determination of the difference between the intake of nitrogen and the amount excreted in urine, faeces, and sweat, together with minor losses by other routes. In most experiments only the nitrogen content of the diet, urine, and faeces has been directly measured. Allowances are made for losses by other routes on the basis of a limited number of published studies. Thus, to allow for these other losses, any estimate of nitrogen balance limited to measurements of diet and excreta in non-growing individuals must be positive if overall body N maintenance is to be achieved.

In using this method to predict protein requirements, the usual procedure is to feed a series of different levels of dietary protein. The requirement is estimated by extrapolating or interpolating the N-balance data to the zero balance point (N equilibrium) for adults or for adequate growth (positive balance) in children. In early studies the levels fed often included one diet period without protein and other levels of intake far below the requirement. However, from studies on experimental animals and on man, it is known that the N-balance response is *not linear throughout the entire submaintenance range*; the slope decreases considerably as intakes producing zero balance are approached and slightly exceeded (*34, 67*).

Accordingly, recent studies have attempted to assess requirements by using several levels of intake that encompass the expected range of requirements. This is one of the reasons why most estimates of requirements based on contemporary studies are higher than those based on data reported in the past. In addition, other variations in experimental design contribute to the differences, such as the level of dietary energy intake and physical activity. In the earlier studies, energy intake was intentionally increased to ensure weight maintenance at low levels of protein intake. However, it is known that this results in more positive (less negative) N balances and therefore lowers the apparent protein requirement (*53, 61*) (section 5.3).

A second problem is the magnitude of the N losses other than from urine and faeces, the most important of which is via the skin. During heavy work in hot climates appreciable amounts of nitrogen are lost in sweat, mainly as urea, although the losses are lower in those who are acclimatized (*68*). There is some evidence of a compensatory reduction in urinary urea output (*69*). The N content of sweat is related to blood urea and both decrease with a low protein intake. Other forms of loss, e.g., in hair clippings and menstrual flow, have been measured in detail in some studies (Annex 6).

In the conventional balance study, these losses are not determined and an estimated allowance is made for them. On the basis of the available evidence this allowance has been set at 8 mg of N/kg per day for adults and 10 mg/kg for children up to the age of 12 years. It is unlikely that a single figure will be applicable under all conditions, but there is no realistic alternative to using this method of correction.

A further important consideration is the length of time needed to achieve a steady state at given levels of protein intake. Because adjustments in urinary N excretion do not occur immediately following a change in N intake, it is necessary to allow an adequate period of time for adjustment of N output to the new N-intake level. Most recent experiments concerned with the determination of N requirements have involved diet periods of 1, 2, or 3 weeks at each intake level. This approach characterizes the so-called "short-term" N balance determinations of protein requirements in man.

The experimental design may be criticized on the ground that the time necessary to achieve a new steady state resulting in zero N balance may in fact be longer than that allowed for in the short-term studies. If this is so, this method will result in overestimation of the requirements. Data from studies on obligatory N losses show that there is initially a sharp drop in urinary N followed by a long period of relatively stable but slowly declining excretion. The major adjustment appears to be complete by days 5–7 in most adults over a range of age and sex categories (*13, 14*) and somewhat sooner in children (*15, 70*). Because of day-to-day variation in urinary N excretion it is difficult to make accurate measurements of the subsequent slope or to prove that it is significantly different from zero. Most adult subjects receiving protein intakes close to their maintenance needs have not shown statistically significant differences in urinary N output when days 5–10 are compared with days 10–15 (*70*). However, in a long-term study of men with a low protein intake (0.36 g of protein/kg), it was shown that subjects required from 8 to 28 days to reach a new steady state.[1] From the little evidence available, it appears that when subjects are fed a fixed protein intake over a long period of time, some do and some do not show a slow drift towards a lower rate of urinary N excretion.[2] Data from a very long-term study of men fed 6.5 g of N/day (~ 0.64 g of protein/kg) show that urinary N continued to fall for at least 90 days and perhaps much longer; the rate of decline after the first 2 weeks was about 0.01 g of N/day, which would be statistically undetectable in short-term studies (*67*).

It has also been claimed that autocorrelation between day-to-day rates of urinary N excretion will bias the interpretation of balance measurements (*73*). Statistically significant autocorrelation has been found in some studies but not in others (*71*).

Because of these limitations of short-term balances, longer-term studies should provide a better basis for determining protein requirements. In principle they permit the measurement of other variables that respond more slowly to dietary inadequacy, such as alterations in lean body mass or growth rate in children. In the few long-term studies that have been reported to date the usefulness of various biochemical and other measurements has been explored, e.g., serum albumin and total body potassium (K), but no sensitive and reliable marker has been found (*56, 74*). There is undoubtedly a need for other criteria of protein nutritional status as a firm basis for estimating requirements.

Clearly, it would be very difficult to carry out a study in which subjects received a range of different intakes, remaining on each one for several months rather than several weeks. Published long-term

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[1] Durkin, N., et al., unpublished data, 1981.

[2] Rand, W.M. & Young, V.R., unpublished observations, 1981.

balances have so far been conducted at only one level of protein intake. However, longer-term studies under somewhat more realistic conditions, in which adequate growth and positive N balance in children and N equilibrium in adults are maintained, provide the best evidence that the level fed is adequate, whether or not it is a minimum figure.

The preceding discussion assumes that the aim of both short-term and long-term balances is to find the minimum protein intake that will maintain the *status quo* in terms of mass of body protein. This aim allows for only minimal changes in protein mass as the body moves from one steady state to another (see section 5.2). Quite large losses of body protein can be supported without loss of life (*75*), but the degree of loss that is compatible with optimal function remains unknown.

5.6 Requirements for essential amino acids

The requirements for essential amino acids have been assessed by nitrogen balance in adults, starting with the classical work of Rose (*76*), by determining the amounts needed for normal growth and N balance in infants and children, and for infants, by comparison with observed intakes of good quality proteins. The report of the 1971 Committee (*12*) contains estimates of the amino acid requirements of infants, older children, and adults. Since then, information has become available on the amino acid requirements of preschool children aged 2–4 years, and the requirements of infants and older children have been reassessed.

Infants. The 1971 Committee (*12*) estimated the amino acid requirements of infants by using the intakes of cow's milk formulae or breast milk that supported satisfactory growth (*77–79*). With the exception of the requirement for tryptophan, the values estimated from the amounts of protein consumed in formulae were lower than those determined by Holt & Snyderman from N balances and the growth of infants given amino acid mixtures (*80*). The lower values are given in Table 4.

Snyderman et al. were also able to maintain satisfactory rates of growth in a small group of infants who consumed a diluted cow's milk formula to which glycine and urea had been added (*81*). These infants were consuming amino acids in amounts slightly below those

Table 4. Estimates of amino acid requirements at different ages (mg/kg per day)[a]

Amino acid	Infants (3–4 months)	Children (2 years)	Schoolboys (10–12 years)		Adults
	(ref. *12*)	(ref. *82, 83*)	(ref. *12*)	(ref. *86*)	(ref. *12*)
Histidine	28	?	?	?	[8–12][b]
Isoleucine	70	31	30	28	10
Leucine	161	73	45	44	14
Lysine	103	64	60	44	12
Methionine + cystine	58	27	27	22	13
Phenylalanine + tyrosine	125	69	27	22	14
Threonine	87	37	35	28	7
Tryptophan	17	12.5	4	3.3	3.5
Valine	93	38	33	25	10
Total essential amino acids	714	352	261	216	84

[a] The pattern of essential amino acid requirements in infants shown in the first column of this table differs somewhat from the pattern in human milk (Table 38), which is richer in sulfur amino acids and tryptophan. The decision (section 7.3.3) to base the scoring pattern for the protein quality of infants' diets on the pattern in human milk will, by comparison with this table, lead to a different estimate. It must, however, be remembered that measurements of the requirements for single amino acids are subject to uncertainty.

[b] Not given in reference *12* (see text).

estimated to be adequate on the basis of the studies of Fomon et al. (*78*).

Preschool children. Data on the amino acid requirements of preschool children are now available (*82, 83*). An experimental design similar to that of Holt & Snyderman was used (*80*). The children received diets consisting of 0.3 g of cow's milk protein/kg per day plus an amino acid mixture in proportions and amounts equal to 0.9 g milk-protein/kg per day. The diets provided 100 kcal$_{\text{th}}$/kg per day (418.4 kJ/kg per day) with proper vitamin and mineral supplements. The single essential amino acid under study was partially replaced in the diet by glycine at five different levels. Nitrogen balance was calculated with an allowance of 8 mg of N/kg per day for integumental losses. It was assumed that a retention of 16 mg of N/kg per day (i.e., 100 mg of protein or about 0.5 g of lean tissue gain/kg per day) allowed for normal growth, and results were validated by N-balance studies conducted on children fed milk or soy protein to assess protein needs. Table 4 summarizes the new requirements. As this table shows, the values for preschool children are closer to those of older children than to those of infants.

Older children. The amino acid requirements proposed by the 1971 Committee (*12*) for boys between 10 and 12 years were based on studies in Japan (*84, 85*). These values represented the lowest amounts of amino acid needed to bring all subjects into positive N balance. The data have been re-examined by a committee in the USA (*86*), which derived estimates of requirements from the information provided on individual subjects. Table 4 gives both sets of estimates. The 1971 Committee's figures are consistently higher than those calculated by the committee in the USA. There are no other studies of amino acid requirements of school-age children, but judging from measurements of N balance in girls of 7–9 years fed two levels of protein, the need for sulfur-containing amino acids is greater than 13 mg/kg and is met by 30 mg/kg (*87*). These discrepancies emphasize the limited and unsatisfactory state of knowledge concerning the amino acid requirements of children.

Adults. The figures for adults in Table 4 summarize the data of the 1971 Committee (*12*) for both sexes together. The figures for men were derived from studies in which the criterion of adequacy was the attainment of positive N balance. In the studies on women a positive balance was not necessarily attained; the authors accepted a balance of 0 ± 5% of intake as the criterion of adequacy. The data for the two sexes are not entirely consistent, but whether the differences are attributable to biological differences in the requirements for individual amino acids or to differences in methodology is not known. The requirement for sulfur-containing amino acids has been confirmed by subsequent N-balance studies (*88*). The report of the 1971 Committee (*12*) does not include a value for histidine. Evidence is now accumulating that histidine is essential even for adults, and that this requirement may be between 8 and 12 mg/kg (*89*). For other essential amino acids, present information is insufficient to provide more precise figures for adult requirements.

The adult requirement for essential amino acids falls more sharply from infancy than does the total protein requirement (section 6). Thus, the proportion of total amino acids (T) that must be supplied as essential amino acids (E) (the E/T ratio) falls with age. This implies that an evaluation of dietary protein quality based on the amino acid requirements or the E/T ratio for infants or young children may underestimate the effectiveness of that protein in meeting the requirements of older children and adults. How this problem is to be dealt with when evaluating local diets is discussed in section 7.

5.7 General comments on methods of assessing protein requirements

In determining protein requirements for maintenance or growth, the present Consultation has relied on direct N-balance studies, although they are not without problems, rather than on the earlier factorial method. The Consultation believes that evidence of N balance in long-term studies constitutes the most acceptable direct evidence. Regrettably, long-term N-balance data are lacking, and the few studies that have been done must be supplemented by results for short-term N balance.

None of the current evidence is entirely satisfactory because there is no method available for the independent validation of an optimal state of protein nutrition. The functional significance of larger and smaller total-body N pools and faster or slower protein turnover rates is unknown. Most biochemical markers (plasma retinol-binding protein, albumin, etc.) are either unchanged even after relatively long periods (30 days or more) of negative N balance or are not readily interpretable (e.g., enzyme changes). There are no functional indicators that can usefully be applied in experimental situations to detect protein inadequacy before clinically detectable changes occur. This area urgently requires further research.

In the final analysis, one would wish to set protein allowances in accordance with such characteristics as health, growth, development, and longevity. This was, in fact, the approach used by our predecessors at the end of the nineteenth and beginning of the twentieth centuries—Voit, Atwater, Benedict, and Cathcart (*90, 91*). The majority view, with Chittenden dissenting, appears to have been that protein intakes well in excess of physiologically determined requirements were associated with active and healthy lives.

However, the evidence on which these observations were based is of limited value. Firstly, most habitual diets derive 10–14% of their energy from protein. Thus, when energy intake rises, so does protein intake and also intakes of many of the nutrients associated with protein in foods, such as the B-group vitamins and trace elements. Secondly, it is obvious that many environmental factors will influence any selected measure of health. Populations that characteristically have higher levels of protein intake tend to live under healthier conditions, whereas those with habitually lower intakes are much more likely to be exposed to parasitic and infectious disease. These confounding factors make it extremely difficult to attempt to draw causal relationships. Thirdly, there are many different measures of health and wellbeing; the criteria are therefore complex and cannot easily be used to set physiological requirements for protein.

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6. ESTIMATES OF ENERGY AND PROTEIN REQUIREMENTS OF ADULTS AND CHILDREN

6.1 Adults

6.1.1 *Energy requirements*

The factors determining energy needs were considered in section 4. As discussed in that section, all energy costs, including total expenditure, are derived as multiples of the basal metabolic rate (BMR). This section is concerned with evaluating these costs.

6.1.1.1 *Basal metabolic rate (BMR).* Since the BMR depends upon both age and body weight, adults of both sexes have been divided into three age ranges—18–30, 30–60, 60+ (sections 3.5.2 and 3.6.1). Within each age range, values for BMR have been obtained from the body weight by the equations shown in Table 5, as discussed in section 4.2.1 (*1*).[1] Table 6 shows that in adults the BMR per kg varies with actual weight. In the report of the 1971 Committee (*1a*) it was assumed that the BMR per kg is constant within each age range. The effect of this change on the prediction of BMR is to increase the estimated requirement of smaller and lighter people and to decrease the requirement of those who are larger and heavier.

Table 5. Equations for predicting basal metabolic rate from body weight (W)[1]

Age range (years)	kcal_{th}/day	Correlation coefficient	SD[a]	MJ/day	Correlation coefficient	SD[a]
Males						
0–3	$60.9W - 54$	0.97	53	$0.255W - 0.226$	0.97	0.222
3–10	$22.7W + 495$	0.86	62	$0.0949W + 2.07$	0.86	0.259
10–18	$17.5W + 651$	0.90	100	$0.0732W + 2.72$	0.90	0.418
18–30	$15.3W + 679$	0.65	151	$0.0640W + 2.84$	0.65	0.632
30–60	$11.6W + 879$	0.60	164	$0.0485W + 3.67$	0.60	0.686
> 60	$13.5W + 487$	0.79	148	$0.0565W + 2.04$	0.79	0.619
Females						
0–3	$61.0W - 51$	0.97	61	$0.255W - 0.214$	0.97	0.255
3–10	$22.5W + 499$	0.85	63	$0.0941W + 2.09$	0.85	0.264
10–18	$12.2W + 746$	0.75	117	$0.0510W + 3.12$	0.75	0.489
18–30	$14.7W + 496$	0.72	121	$0.0615W + 2.08$	0.72	0.506
30–60	$8.7W + 829$	0.70	108	$0.0364W + 3.47$	0.70	0.452
> 60	$10.5W + 596$	0.74	108	$0.0439W + 2.49$	0.74	0.452

[a] Standard deviation of differences between actual BMRs and predicted estimates.

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[1] Since the present report was compiled the data base for the equations contained in reference *1* has been slightly expanded. They, therefore, differ from the equations shown in Table 5 but the differences are negligible.

Table 6. Basal metabolic rate in adult men and women in relation to height and median acceptable weight for height[a] (values given in $kcal_{th}$ with MJ in parentheses)

		18–30 years		30–60 years		>60 years	
Ht (m)	Wt[b] (kg)	Per kg per day	Per day	Per kg per day	Per day	Per kg per day	Per day
Men							
1.5	49.5	29.0 (121)	1 440 (6.03)	29.4 (123)	1 450 (6.07)	23.3 (98)	1 150 (4.81)
1.6	56.5	27.4 (115)	1 540 (6.44)	27.2 (114)	1 530 (6.40)	22.2 (93)	1 250 (5.23)
1.7	63.5	26.0 (109)	1 650 (6.90)	25.4 (106)	1 620 (6.78)	21.2 (89)	1 350 (5.65)
1.8	71.5	24.8 (104)	1 770 (7.41)	23.9 (99)	1 710 (7.15)	20.3 (85)	1 450 (6.07)
1.9	79.5	23.9 (100)	1 890 (7.91)	22.7 (95)	1 800 (7.53)	19.6 (82)	1 560 (6.53)
2.0	88	23.0 (96)	2 030 (8.49)	21.6 (90)	1 900 (7.95)	19.0 (80)	1 670 (6.99)
Women							
1.4	41	26.7 (112)	1 100 (4.60)	28.8 (120)	1 190 (4.98)	25.0 (105)	1 030 (4.31)
1.5	47	25.2 (105)	1 190 (4.98)	26.3 (110)	1 240 (5.19)	23.1 (97)	1 090 (4.56)
1.6	54	23.9 (100)	1 290 (5.40)	24.1 (101)	1 300 (5.44)	21.6 (90)	1 160 (4.85)
1.7	61	22.9 (96)	1 390 (5.82)	22.4 (94)	1 360 (5.69)	20.3 (85)	1 230 (5.15)
1.8	68	22.0 (92)	1 500 (6.28)	20.9 (87)	1 420 (5.94)	19.3 (81)	1 310 (5.48)

[a] BMR from equations in Table 5, rounded to 10 $kcal_{th}$.

[b] Weight taken as median acceptable weight for height; body mass index (Wt/Ht^2) = 22 in men, 21 in women (see Annex 2).

As discussed in section 3, the BMR may be determined either from the actual weight, if this is known, or from the median weight, according to age, sex, and height. Some examples of the differences produced by the two methods are shown in Table 7. The choice of method will depend upon the circumstances and objectives of the user. It will be seen that at a given height the BMRs of subjects at

Table 7. Examples of predicted BMR in subjects of the same height but different weights, predicted (**A**) from actual weight; (**B**) from median acceptable weight for height

	Man, age 40, height 1.8 m			Woman, age 25, height 1.5 m		
	Position in range[a]			Position in range[a]		
	Upper	Median	Lower	Upper	Median	Lower
BMI[b]	25	22	20	24	21	19
Wt (kg)	81.0	71.3	64.8	54.0	47.2	42.7
(**A**) BMR[c] from actual Wt						
$kcal_{th}$/day	1 820	1 710	1 630	1 290	1 190	1 120
MJ/day	7.61	7.15	6.82	5.39	4.98	4.68
(**B**) BMR from median Wt						
$kcal_{th}$/day	1 710	1 710	1 710	1 190	1 190	1 190
MJ/day	7.15	7.15	7.15	4.97	4.97	4.97

[a] Acceptable range of BMI (see Annex 2A).

[b] Body mass index = $Wt(kg)/Ht^2(m)$.

[c] Predicted from equations in Table 5.

the extremes of the acceptable range of weight differ from those at the median weight by less than 10%. .

The converse situation is when subjects of the same weight vary in height and hence in body mass index (BMI). Except in the elderly, such variations, within the acceptable range of weight for height, have no importance in men and relatively little importance in women. Examples of the effect of including height in the prediction of BMR are shown in Annex 1.

6.1.1.2 *Baseline energy need.* Since the BMR is measured in the postabsorptive state and at complete rest, for an individual to survive an addition has to be made to cover the metabolic response to food (section 4.2.4) and the energy cost of increased muscle tone and minor movement. A value of 1.4 times the BMR during waking hours, for the energy cost of activities such as washing, dressing, and short periods of standing, can be derived from published figures (*2*). If 8 hours a day are spent in bed at the basal rate of energy expenditure, then the requirement over a period of 24 hours amounts to 1.27 times the BMR $((\frac{2}{3} \times 1.4) + (\frac{1}{3} \times 1.0))$. It should be emphasized that this requirement allows for minimal movement; it is not compatible with long-term health and makes no allowance for the energy needed to earn a living or prepare food. It could be called the *survival requirement* and is of practical value in conditions of crisis only, for estimating the short-term needs of totally inactive dependent people.[1]

6.1.1.3 *Energy needs for occupational activities.* The energy need will vary with the type of occupation, the time spent in doing the task, and the size of the individuals concerned. Annex 5 provides estimates of the requirements per minute for various occupations. These are expressed as multiples of the basal metabolic rate, and thus include the cost of minor movement, muscle tone, and the specific metabolic response to food.

Classification of occupational activities. Traditionally the occupations of men and women have been classified into those which involve light, moderate, and heavy physical activity. This has facilitated the broad assessment of the energy requirements of

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[1] See the footnote on page 78.

populations and has been helpful when the energy needs of a particular occupational group have not been specifically studied. Annex 5 lists the activities and occupations that can be classified in this way.

Table 8 (page 76) shows how approximate values for the energy costs of occupations involving the three degrees of activity have been obtained. On this basis one can estimate the *gross* energy expenditure on occupational work at light, moderate, and heavy levels of activity as 1.7, 2.7, and 3.8 times the basal metabolic rate in young men, and 1.7, 2.2, and 2.8 times the BMR in young women.

Clearly, care is needed to ensure an accurate description of the activity and the time spent on it. Thus the energy demand on workers undertaking specific jobs, such as farming, mining, shipbuilding, or tree felling, may vary enormously, depending on the degree of mechanization.

For estimating the requirement per day, weekly working hours have to be averaged over 7 days. Thus for those who work for 8 hours per day for 5 days a week, the average would be 5 hours 43 minutes daily over the entire week. For other groups with different work patterns the calculation of time will have to be adjusted.

6.1.1.4 *Discretionary activities*. The principles underlying the inclusion of discretionary activities when estimating energy requirements have been given in sections 3 and 4. Some activities will be short-lived but require considerable rates of energy expenditure, whereas others have only modest costs but are undertaken for longer periods. Socially desirable physical activities have been calculated to be equivalent to walking, but may involve a variety of activities, of which some examples were given in section 4.2.3. It is likely that many of these discretionary activities, particularly the more vigorous ones, will not be performed every day, and it is only possible to make a nominal allowance for them.

In sedentary people the allowance for discretionary activity includes provision for short periods of vigorous exercise to maintain physical fitness and promote cardiovascular health. Five times the BMR represents a steady state of exercise at about 60% of maximal work-load (*5*). In this report 20 minutes a day is suggested as a reasonable period of time for such exercise. This is unlikely to be excessive, since in one study it was shown that adolescent boys need at least one hour per day at this rate to achieve a significant increase in aerobic capacity (*6*).

The energy requirements of the elderly differ from those of the young not only because they often reduce their occupational activities, but also because their basal energy requirements decline, as discussed in section 4.3. An additional allowance has been made for an extra hour of socially desirable activity at this age.

6.1.1.5 *Estimating total energy requirements.* Once the separate components of energy expenditure have been identified and evaluated, the total requirement can be calculated. Some examples are shown in Tables 9–14. As far as possible, these have been calculated from observed patterns of activity described in the literature. On the basis of such patterns, approximate estimates of the total daily energy expenditure corresponding to light, moderate, and heavy work can be derived as multiples of the BMR. These estimates are shown in Table 15.

It must be emphasized that these figures are intended to be general guidelines. As far as possible, users should make their own calculations, according to the characteristics of the population concerned. This could be done in two stages. The first step is to develop the appropriate BMR factor. Adjustments can readily be made to accommodate differences in the time spent at work and in discretionary activity. Most occupations involve static activity which develops muscle strength but not cardiorespiratory efficiency. In general, therefore, discretionary activity of a dynamic nature is beneficial. However, this type of exercise may not be possible for those whose work involves heavy labour and physical fatigue. All additional times when individuals are not engaged in occupational or discretionary activities are considered to require a minimum energy expenditure at 1.4 times the BMR, except for the 8 hours assigned to sleeping at a rate equal to the BMR.[1]

The second step is to use the equations in Table 5 to obtain the value for the BMR appropriate for the body weight. For convenience section 8 gives tables of the total daily energy

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[1] The evidence available was insufficient to enable the Consultation to recommend an operational "maintenance" requirement. Any figure chosen would reflect a value judgement on what levels of activity above the minimum for survival could be appropriately included in the term "maintenance" (see page 73). The cost of an additional 1.5 hours a day of walking or about 2 hours of standing would increase energy expenditure to 1.4 times the BMR over 24 hours (*3, 4*). This figure should provide a guide for assessing the maintenance requirements until further published information becomes available.

Table 8. Derivation of average values of the energy cost of three grades of physical activity at work, for women and men[a]

	Women[b]				Men[c]			
	Cost/min		Average cost x BMR		Cost/min		Average cost x BMR	
	(kcal_{th})	(kJ)	(gross)	(net)	(kcal_{th})	(kJ)	(gross)	(net)
Light work								
75% of time sitting or standing	1.51	6.3			1.79	7.5		
25% of time standing and moving	1.70	7.1			2.51	10.5		
Average	1.56	6.5	1.7	0.7	1.99	8.3	1.7	0.7
Moderate work								
25% of time sitting or standing	1.51	6.3			1.79	7.5		
75% of time spent on specific occupational activity	2.20	9.2			3.61	15.1		
Average	2.03	8.5	2.2	1.2	3.16	13.2	2.7	1.7
Heavy work								
40% of time sitting or standing	1.51	6.3			1.79	7.5		
60% of time spent on specific occupational activity	3.21	13.4			6.22	26.0		
Average	2.54	10.6	2.8	1.8	4.45	18.6	3.8	2.8

[a] Times and energy costs of sitting, standing, moving around, and work tasks are composite values derived from published and unpublished data (Annex 5).

[b] Based on young adult females (18–30 years), Wt 55 kg, BMR 0.90 kcal_{th} (3.8 kJ)/min (Table 5).

[c] Based on young adult males (18–30 years), Wt 65 kg, BMR 1.16 kcal_{th} (4.9 kJ)/min (Table 5).

Table 9. Energy requirement of a male office clerk (light activity work)

Age 25 years, weight 65 kg, height 1.72 m, BMI 22
Estimated basal metabolic rate: 70 kcal_{th} (290 kJ) per hour

	hours	kcal_{th}	kJ
In bed at 1.0 × BMR	8	560	2 340
Occupational activities at 1.7 × BMR	6	710	2 970
Discretionary activities:			
– Socially desirable and household tasks at 3.0 × BMR	2	420	1 760
– Cardiovascular and muscular maintenance at 6 × BMR	⅓	140	580
For residual time, energy needs at 1.4 × BMR	7⅔	750	3 140
Total = 1.54 × BMR		2 580	10 780

Note: These data may be compared with those from Garry et al. (*7*) on office clerks in the mining industry, who on average measured 1.72 m and weighed 64.6 kg with an energy expenditure of 11 715 kJ per day. The energy spent during sleep was 17.9%, in occupational activities 31.8%, and in non-occupational activities 50.3%. This compares with the present suggested proportions for the population of 19.3%, 32.8%, and 47.9% for each group of activities.

Table 10. Energy requirement of a subsistence farmer (moderate activity work)

Age 25 years, weight 58 kg, height 1.61 m, BMI 22.4
Estimated basal metabolic rate: 65 kcal_{th} (273 kJ) per hour

	hours	kcal_{th}	kJ
In bed at 1.0 × BMR	8	520	2 170
Occupational activities at 2.7 × BMR	7	1 230	5 150
Discretionary activities:			
– Socially desirable and household tasks at 3.0 × BMR	2	390	1 630
– Cardiovascular and muscular maintenance—not needed if moderately active	–	–	–
For residual time, energy needs at 1.4 × BMR	7	640	2 680
Total = 1.78 × BMR		2 780	11 630

Note: These data compare with 24-year-old Kaul males in Papua New Guinea, 1.62 m tall and weighing 57.4 kg. Their actual energy expenditure was 10 960 kJ (*8*).

Table 11. Energy requirement for a male engaged in heavy work

Age 35 years, weight 65 kg, height 1.72 m, BMI 22
Estimated basal metabolic rate: 68 kcal_{th} (284 kJ) per hour

	hours	kcal_{th}	kJ
In bed at 1.0 × BMR	8	545	2 280
Occupational activities at 3.8 × BMR	8	2 070	8 660
Discretionary activities at 3.0 × BMR	1	205	860
For residual time, maintenance energy needs at 1.4 × BMR	7	670	2 800
Total = 2.14 × BMR		3 490	14 580

Table 12. Energy requirement of a healthy, retired elderly man

Age 75 years, weight 60 kg, height 1.6 m, BMI 23.5
Estimated basal metabolic rate: 54 kcal_{th} (225 kJ) per hour

	hours	kcal_{th}	kJ
In bed at 1.0 × BMR	8	430	1 810
Occupational activities	0	0	0
Discretionary activities:			
– Socially desirable at 3.3 × BMR[a]	2	355	1 490
– Household tasks at 2.7 × BMR	1	145	610
– Cardiovascular and muscular maintenance at 4 × BMR	⅓	70	300
For residual time, energy needs at 1.4 × BMR	12⅔	960	4 020
Total = 1.51 × BMR		1 960	8 220

[a] Because the elderly man has no occupational demands on his time, an extra hour has been allocated for walking and other similar activities.

Table 13. Energy requirement of a housewife in an affluent society

Age 25 years, weight 55 kg, height 1.5 m, BMI 24
Estimated basal metabolic rate: 54.5 kcal$_{th}$ (230 kJ) per hour

	hours	kcal$_{th}$	kJ
In bed at 1.0 × BMR	8	435	1 820
Occupational activities:			
– Extra housework,[a] at 2.7 × BMR	1	150	630
Discretionary activities:			
– Socially desirable and household tasks at 3.0 × BMR	2	330	1 380
– Cardiovascular and muscular maintenance at 6 × BMR	⅓	110	460
For residual time, energy needs at 1.4 × BMR	12⅔	965	4 040
Total = 1.52 × BMR		1 990	8 330

[a] Housewives are envisaged as needing to spend an extra hour, over and above the hour per day applicable to all adults, in household tasks requiring moderately high physical activity (i.e., at a *gross* cost of 2.7 × BMR). The remaining household activities—such as sewing or knitting, ironing, some parts of food preparation, etc.—are included in maintenance.

Table 14. Energy requirement of a rural woman in a developing country

Age 35 years, weight 50 kg, height 1.6 m, BMI 19.5
Estimated basal metabolic rate: 53 kcal$_{th}$ (220 kJ) per hour

	hours	kcal$_{th}$	kJ
In bed at 1.0 × BMR	8	425	1 780
Occupational activities:			
– Housework, preparing food, etc. at 2.7 × BMR	3	430	1 800
– Working in fields, at 2.8 × BMR	4	595	2 490
Discretionary activities at 2.5 × BMR	2	265	1 110
For residual time, energy needs at 1.4 × BMR	7	520	2 180
Total = 1.76 × BMR		2 235	9 360

Table 15. Average daily energy requirement of adults whose occupational work is classified as light, moderate, or heavy, expressed as a multiple of BMR

	Light	Moderate	Heavy
Men	1.55	1.78	2.10
Women	1.56	1.64	1.82

requirement for sex and age at different body weights and different values of the BMR factor.

6.1.2 *Adult protein requirements*

Young men. To derive the protein requirement of young male adults, the Consultation reviewed evidence from both short- and longer-term nitrogen balance studies. The short-term studies accepted for this purpose are summarized in Table 16. In all these studies protein was fed at several levels below and above an amount expected to promote N equilibrium (zero balance). The aggregated data provide an estimated mean requirement of 0.63 g/kg of highly digestible, good-quality protein. This mean value is slightly higher than the safe level recommended by the 1971 Committee (*1a*), which was intended to be 2 SD above the mean requirement. As discussed in section 5.5, three factors contribute to the difference in estimates: studies before 1971 involved relatively high energy intakes, promoting more positive N balances; many of the earlier balance

Table 16. Summary of results of representative short-term N-balance studies in healthy young men

Protein source	No. of subjects	Mean requirement[a] (g protein/kg per day)	Coefficient of variation (CV)	Reference
Single, high-quality proteins				
Egg	8	0.65	6.8	(*10*)
Egg	31	0.63	–	(*11*)
Egg	7	0.58	19.0	(*15*)
Egg	11	0.69	–	(*12*)
Egg-white	6	0.74	10.8	(*17*)
Egg-white	9	0.49	18.2	(*13*)
Beef	7	0.56	11.5	(*9*)
Casein	7	0.58	–	(*14*)
Fish	7	0.71	19.1	(*16*)
Average		0.626		

Usual, mixed diets

Country	No.	Requirement	CV	Reference
China	10	0.99	11.6	(*20*)
India	6	0.54	11.6	(*19*)
Turkey	11	0.65	13.7	(*21*)
Brazil	8	0.70	14.6	(*22*)
Chile	7	0.82	14.2	(*10*)
Japan	8	0.73	27.1	(*16*)
Mexico	8	0.78	17.4	(*18*)
China, Province of Taiwan	15	0.80	20.3	(*15*)

[a] Recalculation with 8 mg of N/kg per day for miscellaneous losses.
Pooled coefficient of variation = 16.2%.

Table 17. Summary of longer-term balance studies in young men receiving low and constant intakes of good-quality protein[a]

Source of protein and intake level	No. of subjects	Total length of study (days)	Summary evaluation of major findings	Reference
Egg: 0.59 g/kg per day	6	81 – 89	4 subjects in negative N balance. Body composition changes. Abnormal blood biochemical changes	*(23)*
Egg: 0.57 g/kg per day	6	77 – 87	Balance improved with excess energy intake but N balance negative in 5 subjects at estimated required energy intakes. Weight gain at high energy intake. Abnormal biochemical changes reversed with increase in protein intake	*(24)*
Egg: 0.57 g/kg per day	4	59 – 77	3 subjects in negative balance; improved by increased energy intake	*(25)*
Egg: 0.57 g/kg per day + a nonessential amino acid mixture (= 0.23 g protein/kg per day)	6	58 – 79	Addition of non essential amino acid improved N balance. Body weight stable. Lower energy intakes required to maintain N balance than at lower N intake	*(26)*
Egg: 0.36 g/kg per day	6	77	2 subjects in negative balance; 3 in marginal balance. 5 subjects showed weight loss. No adverse biochemical changes, except for small decrease in Hb[b]	
Milk: 0.61 g/kg per day	4 2	36 24	N balance in marginal range. No significant changes in body weight or Hb	*(27)*

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[a] Interpretation of the published data takes into consideration the present estimate of 8 mg of N/kg per day for miscellaneous N losses. This may be an overestimate when N intake, and hence blood urea N and sweat N concentrations are low.

[b] Durkin, N., et al. unpublished data, 1981.

studies did not include enough levels of intake in the region of zero balance, so that the efficiency of utilization was overestimated; finally, the 1971 Committee's figures allowed 5 mg of N/kg for miscellaneous losses, in contrast to the 8 mg/kg assumed by the present Consultation.

A few longer-term balances (1–3 months) have been measured, at single levels of intake, since the report of the 1971 Committee was published. Taken as a group, these studies provide information about the range of requirements for protein. A total of 28 men were fed egg or milk protein at about the 1973 safe level (0.57–0.61 g/kg) in five separate studies (Table 17). N balance was negative in 12 men and marginal (within laboratory error) in 6 others. In another study (Table 17) five of six men fed a lower level (0.36 g of egg protein/kg) for 77 days lost weight; one man was in positive N balance, two were in negative balance, and values for the other three were in the marginal range. Unpublished studies of men fed 0.73–0.80 g/kg show that N balance was adequately maintained in all subjects at that level (*28, 29*). These results suggest that 0.36 g/kg may be regarded as approximating to 2 SD below the mean requirement or less and 0.73–0.80 g/kg as 2 SD above the mean or more. The average amount fed, 0.58 g/kg, is a reasonable estimate of the mean requirement of healthy young men whose habitual intake is well above this level.

In a long-term study carried out for another purpose (*30*), 21 men received a good mixed diet supplying 6.5 g of N/day or about 0.64 g of protein/kg. Only urinary N was measured, but at 109 days the average excretion was 5.2 g, indicating that on the average the men were in N equilibrium. Four men continued on the diet for much longer; average urinary N was 5.19, 5.08, and 5.07 g at 319, 410, and 525 days, respectively. The original records of this study cannot be located so that it is not possible to determine whether some men were consistently in negative balance, or whether most or all subjects were in balance averaged across several days. Body weight was 63 kg initially and 62 kg at day 250. These findings suggest that the average figure proposed at least meets and may exceed the average requirement of adapted individuals.

In the absence of better estimates of the average requirement, the Consultation decided to accept the mean of the values derived from the two sets of balance data. The mean values of 0.63 g/kg derived from the short-term balance studies and 0.58 g/kg from the long-term balance studies give a figure of 0.605 which could for most purposes be rounded to 0.6 g/kg per day, representing the *average requirement* for proteins of high quality, such as those from meat, milk, egg, and fish. The Consultation recognized that this value may be higher than the requirement of fully adapted persons but there was not enough information to improve this estimate.

In order to translate this estimate of average requirement into a level sufficient to cover individual variations within a population group (*safe level of intake* as defined in section 2), the coefficient of variation of the requirements must first be estimated. To obtain the coefficient of variation in the absence of data on variability from long-term studies at various levels of protein intake, the Consultation used the available information from short-term N-balance studies performed at different levels of protein intake around zero N balance (Table 16). These data show that the coefficient of variation in estimates of requirements averaged 16.2%. Assuming that this variation is approximately equally partitioned between and within subjects (where the within-subject variability includes measurement error as well as biological variability), the Consultation estimated that the true coefficient of variation of the protein requirements of adults was 12.5%. Consequently, a value of 25% (2 SD) above the average physiological requirement would be expected to meet the needs of all but 2.5% of individuals within the population. This level of good-quality protein (0.75 g/kg per day) is, therefore, thought to correspond to the lower end of the safe range of protein intakes.

Nitrogen balance data are also available from short-term studies in which men were fed several levels of protein from ordinary mixed diets (Table 16). These studies predict the mean daily dietary requirement to be 0.54–0.99 g of protein per kg of body weight. The diets required in larger amounts are mainly those that are poorly digested and the requirement for net absorbed protein does not appear to differ between the high-quality proteins and practical adult diets. The method of correcting for digestibility is discussed in section 7.3.

Young women. There are less extensive data available for adult women. The 1971 Committee (*1a*) concluded that obligatory urinary nitrogen losses per basal kcal_{th} do not differ between young men and women and more recent studies support this conclusion (*31*). Furthermore, on the basis of short-term N-balance studies (*32*) performed on young women receiving proteins from different sources, there is no evidence to suggest that the efficiency of utilization of dietary protein for meeting their physiological requirements is substantially different from that of young adult men when expressed per unit of body weight.

In industrialized countries young women generally have a higher proportion of body fat than young men and therefore a lower metabolic mass per kg. This has not been found in some less privileged communities (*33*). However, it would be unwise to suppose that it is always the case. Therefore, the Consultation concluded that there is no justification for making a distinction between adult males and females when setting the safe intake of protein. Accordingly, the safe intake of good-quality, highly digestible protein was set at 0.75 g/kg per day for both sexes.

Older adults and the elderly. Since many age-related body changes appear to occur continuously throughout adult life, protein allowances for adults should ideally be those that best preserve bodily functions from early adulthood to old age. Protein needs might be expected to change progressively during aging, since body composition, physiological functional capacity, physical activity, total food intake, and frequency of disease alter with age (see sections 3 and 4). However, there is not, at present, sufficient information to establish firm recommendations based on such a continuum. Nevertheless, the elderly make up an important section of the population for whom estimates of protein requirements must be developed as a public health measure.

Some recent observations on age-related changes in body composition and protein metabolism, especially relating to muscle, suggest that utilization of dietary protein and essential amino acids may differ between the young and old adult (*34*). Direct studies of the amount of dietary protein needed to bring older adults and the elderly into N equilibrium and maintain protein nutritional status are limited (*34*). Unfortunately, four recent studies (*35–38*) do not provide a consistent picture of the protein needs of the elderly. In one case, 0.8 g/kg per day of egg protein was not enough to maintain N balance in the majority of elderly men and women over a 30-day period (*38*). However, another study, on a group of slightly less elderly subjects, found this level of protein to be adequate (*36*). In both these studies body weight was maintained but energy intake was less in the former than in the latter, suggesting that activity patterns may have been different in the two groups.

It is improbable that high intakes of protein can prevent the aging process in adults, since measurements showing loss of lean body mass and tissue function with age have been made in Western countries in which the daily consumption of protein by adults is customarily about twice the estimated lower limit of the safe protein intake of 0.75 g/kg. It is not known whether populations living at the level of 0.75 g/kg of dietary protein or less show different losses of lean body mass and tissue function.

In view of these considerations, the Consultation concluded that the safe intake of protein should not be lower than 0.75 g/kg per day for older adults and the elderly. This figure is higher than that for younger adults in relation to lean body mass, because it is an accepted fact that protein utilization is less efficient in the elderly.

6.2 Pregnancy and lactation

6.2.1 *Requirements during pregnancy*

6.2.1.1 *Energy.* During pregnancy extra energy is needed for the growth of the fetus, placenta, and associated maternal tissues. Basal metabolism rises (*37–41*), partly due to the increased mass of active tissue (fetal, placental, and maternal), the cost of increased maternal effort (e.g., cardiovascular and respiratory work), and the cost of tissue synthesis.

In well nourished populations in the developed countries, the weight gain during pregnancy is about 12.5 kg and the median infant birth weight is 3.3 kg, with a coefficient of variation of 15%. The average extra energy cost of this typical pregnancy has been calculated to be about 335 MJ (80 000 kcal_{th}) over the 9-month period (*42*), distributed, according to the report of the 1971 Committee (*1a*), as an extra 630 kJ (150 kcal_{th})/day during the first trimester and 1465 kJ (350 kcal_{th})/day during the second and third trimesters.

It is difficult to calculate accurately the energy needs during pregnancy. Women of small stature tend to have small babies and would logically fall in the lower range of normal weight gains and hence need less additional energy than the average. Obese women need to gain less fat than slimmer women, and women who are underweight for their height should need to gain more than the average. The extra dietary energy requirement in pregnancy also depends on the extent to which mothers can and do reduce their physical activity. It is clearly desirable to increase dietary intake to spare maternal tissue, allow for satisfactory growth of the fetus, adnexa, and breast tissue, and to sustain a desirable pattern of physical activity. The need for generous fat reserves is arguable, but deposition of some fat is associated with a more satisfactory infant birth weight.

Many recent studies of food intakes of well nourished pregnant women (*43*) indicate that these extra energy requirements for tissue deposition are not always accompanied by commensurate increases in intake. Nevertheless, women receiving less than these extra energy intakes seem to deposit enough extra body fat to provide the reserve needed for subsequent lactation, and the fetal and maternal tissues grow satisfactorily (*44*). Although the evidence is only tentative, it appears that the physical activity of such women is reduced. It is also possible that metabolic changes occur in pregnancy that result in a greater economy of energy utilization. Some (*41, 45*) but not all (*46*) studies of well nourished pregnant women indicate that the slowing of self-paced work, e.g., climbing stairs, is usual, so that the energy expended per unit time is maintained at approximately the same level as in the non-pregnant state. However, the energy cost of fixed-pace work is increased, as would be expected from the increases in BMR and body mass, and shows no evidence of improved efficiency under conditions of unrestricted food intake.

If women begin pregnancy with marginal nutritional reserves (e.g., some teenagers in developed countries and many women in developing countries), and if they cannot reduce their previous level of activity, it was the Consultation's view that every effort should be made to provide the full energy allowance.

Because some fat should be deposited early in pregnancy, and because appetite and periodic work requirements vary greatly, there is little evidence to suggest that the extra energy requirement differs between the three trimesters. The Consultation advised an average addition of 1200 kJ (285 kcal_{th}) daily throughout pregnancy. Where healthy women reduce their activity, it is considered reasonable to reduce the average additional allowance to 840 kJ (200 kcal_{th}) daily.

6.2.1.2 *Protein.* The total protein requirement of a woman gaining 12.5 kg during pregnancy and delivering a 3.3-kg infant has been estimated to be 925 g (*42*), or 3.3 g per day throughout pregnancy. The rate of storage is not constant; estimates provided for the first, second, third, and fourth quarters are, respectively, 0.64, 1.84, 4.76, and 6.10 g of protein per day. Previous committees have used these figures to derive estimates of the extra protein needs of pregnant women.

A second approach has been to study protein needs during pregnancy by N balance. These studies indicate that in the second half of pregnancy, there are retentions about 50% greater than can be accounted for by the tissues included in the sum given above (fetus, placenta, maternal tissues, and blood). The difference between the two estimates is about 330 g of protein, or approximately 1.6 kg of lean body mass. If the higher figure predicted from N balance is correct, then the amount of fat storage during the second half of pregnancy must be far lower than is currently supposed. Analysis of the regression of N balance on weight gain measured in a recent study (*47*) shows the composition of the gain in the second half of pregnancy to be 12% protein, a figure which is compatible with the body composition of the newborn (see section 3.3). There are not sufficient data for the first half of pregnancy to enable a judgement to be made on the quality of the available information.

Clearly, these discrepancies merit further investigation, but for the time being the Consultation felt that protein needs should continue to be assessed on the calculated increment of 925 g protein, the average gain, plus 30% (2 SD of birth weight), which should cover the protein gains during pregnancy of nearly all normal women. These figures for gain must be adjusted for the efficiency with which dietary protein is converted to fetal, placental, and maternal tissues. There is no direct evidence on this subject. Two studies (*48, 49*) in which graded N levels, all presumed to be above requirement, were fed to pregnant women indicate the efficiency of utilization to be low (25–35%) and quite variable. At intakes nearer the requirement, the efficiency is unlikely to be so low, and therefore an efficiency factor of 0.70, derived from growth data in children (see Table 6) is accepted as applying also to pregnant women. The safe levels of additional protein computed in this manner are 1.2 g, 6.1 g, and 10.7 g per day in the 1st, 2nd, and 3rd trimesters, respectively (Table 18). However, there is evidence (*50*) from animals that more protein may be deposited early and somewhat less very late in pregnancy so that the distribution of deposition by trimesters may be arbitrary. Thus it is estimated that the protein requirement should be increased by an average of 6 g/day throughout pregnancy. These

Table 18. Safe level of additional protein during pregnancy

Trimester	N gain (g/day)[a]		Efficiency[b]	Additional protein[c] required
	(Average)	(+ 30%)	(0.70)	(g/day)
1	0.104	0.14	0.20	1.2
2	0.525	0.68	0.98	6.1
3	0.922	1.20	1.71	10.7

[a] Estimated tissue N gained in a pregnancy producing a 3.3-kg infant; CV of birth weight 15%.
[b] Assuming 70% efficiency of conversion of dietary to tissue protein (see text).
[c] In terms of absorbed protein.

amounts should be added to the non-pregnant allowance and the sum corrected for digestibility (see section 7.3).

More work is required in this area of crucial importance to maternal and child health, and the Consultation recommended that it should be made a research priority.

6.2.2 *Requirements during lactation*

6.2.2.1 *Energy*. The energy cost of lactation is the energy content of the milk secreted plus the energy required to produce it. The 1971 Committee (*1a*) based its allowance for lactation on the assumption that about 850 ml of milk with an energy content of 3 kJ (0.72 kcal$_{th}$)/ml is secreted daily, with an 80% efficiency of conversion of dietary energy to milk energy. Thus, average milk production was assumed to demand 3.1 MJ (750 kcal$_{th}$)/day. Since then, WHO has sponsored a collaborative study of breast-milk volume and composition (*51*) that suggests a slight revision of the figures. In the five populations examined (Guatemala, Hungary, Philippines, Sweden, Zaire), the volume of milk ingested by infants increased between the second and third months and then remained relatively stable until 6 months. Very few data are available from Western countries after 6 months of age. In the studies in the developing countries, milk consumption fell between the sixth and twelfth months and the level was even further reduced in the second year (Table 19). Among these five populations, breast-milk consumption in the first few months was lower for infants whose birth weights had been lower.

The present analysis of the energy requirements for lactation is based on the median milk consumption of breast-fed Swedish infants for the first 6 months and on more limited data from all populations for the later periods. Median milk volume is close to the mean value

Table 19. Median breast-milk secretion and energy cost of lactation

Month	Median volume[a]	Energy content of milk[b]		Energy cost of lactation[c]	
	(ml/day)	(kcal_{th}/day)	(kJ/day)	(kcal_{th}/day)	(kJ/day)
0– 1	719	503	2105	629	2630
1– 2	795	556	2326	695	2908
2– 3	848	594	2485	742	3105
3– 6	822	575	2405	719	3008
6–12	600	420	1757	525	2197
12–24	550	385	1610	481	2012

[a] Data derived from the results of the WHO Collaborative Study on Breast-feeding (*51*).
[b] Taken as 0.7 kcal_{th} (2.9 kJ) per ml.
[c] Assumed efficiency of conversion 80%.

and the coefficient of variation is about 12.5%. Consumption data have been adjusted upwards by 6% to compensate for an observed underestimation of milk secreted versus milk consumed (*25*). The WHO study (*51*) found the average energy content of breast milk to be 2.9 kJ (0.70 kcal_{th})/ml, which agrees with earlier estimates (*52, 53*). Since there is no new information, the efficiency of conversion of food energy to milk is taken to be 80%. The resulting values are given in Table 19.

If maternal reserves have not been depleted during pregnancy, the amount of dietary energy needed by the average woman for lactation should not be higher than that computed in Table 19, plus the energy required for basal metabolism and daily activity. The pattern of activity of lactating women may be changed, depending upon the circumstances of life. A woman may spend 2–2 ½ hours a day breast-feeding; this is described as "active seated work" (*54*).

There is no evidence yet available to support the suggestion that the BMR may also be altered during lactation. It has been postulated that an enhanced efficiency of energy metabolism might continue from pregnancy into lactation; studies on energy metabolism during lactation, as well as in pregnancy, are clearly a priority for future research.

If the recommendations for pregnancy have been met, the average woman will start lactation with some 150 MJ (36 000 kcal_{th}) of fat reserves. A normal body composition should be re-established within 6 months by utilizing this reserve, which would thus provide about 835 kJ (200 kcal_{th}) per day. In this case, the additional average energy requirement during the first 6 months of lactation would be about 2090 kJ (500 kcal_{th})/day, rather than the 2930 kJ (700 kcal_{th})/ day indicated in Table 19. Allowances during this and subsequent periods will need to be adjusted according to maternal fat stores and patterns of activity. During the later stages of lactation the full allowance of about 2090 kJ (500 kcal_{th})/day should be provided. This requirement must be increased if more than one child is being breast-fed.

6.2.2.2 *Protein requirements during lactation.* The average protein content of breast milk ($N \times 6.25$) has been taken as 1.15 g per 100 ml, except during the first month, when the value is approximately 1.3 g per 100 ml (*51*) (see section 6.3.2). It is accepted that, as for growth in children, an efficiency factor of 70% is necessary to adjust for the conversion of dietary protein to milk protein. While there may be a small amount of tissue protein available from accretion during pregnancy, e.g., from involution of the uterus, this is not a significant factor in providing the extra requirement for lactation.

The coefficient of variation of breast-milk volume has been taken in the previous section as 12.5%. The safe level of provision for the mother should allow for those who are producing, or are capable of producing, more than average amounts of milk. Upward adjustment of the median milk volume, and hence the amount of protein secreted, by 2 SD allows for this.

The figures in Table 20 suggest a safe level of extra protein intake of about 16 g per day during the first 6 months of lactation, 12 g per day during the second 6 months, and 11 g per day thereafter. These amounts should be added to the normal estimate of the woman's protein requirement and corrected for the digestibility of the dietary protein (section 7.3).

Table 20. Extra protein requirements for lactation

Month	Breast milk secreted		Maternal extra protein requirement (g/day)	
	Volume[a] (ml/day)	Protein[b] (g/day)	Average[c]	+ 2 SD[d]
0 – 1	719	9.3	13.3	16.6
1 – 2	795	9.1	13.0	16.3
2 – 3	848	9.75	13.9	17.3
3 – 6	822	9.45	13.5	16.9
6 – 12	600	6.9	9.9	12.3
12 – 24	550	6.3	9.0	11.3

[a] Data derived from the results of the WHO Collaborative Study on Breast-feeding (*51*).

[b] Average protein content taken as 1.3 g per 100 ml in first month; thereafter 1.15 g (see section 6.2.2.2).

[c] Allowing for 70% efficiency of utilization.

[d] CV of infant's birth weight taken as 12.5%.

6.3 Infants, children, and adolescents

6.3.1 *Energy requirements*

Although, in principle, it would be desirable to determine the requirements of children, in the same way as for adults from measurements of energy expenditure, this approach involves many difficulties in practice. Information is indeed available on the BMRs of children of all ages for which prediction equations are given in Table 5. However, in young infants, in whom the requirement for growth is a substantial component of the total requirement for energy, there are large variations within the normal range, in the rate of growth, and probably also in the composition of the tissue laid down. Moreover, for both infants and children, it is not possible to specify with any confidence the allowance that should be made for a desirable level of physical activity. We have therefore followed the example of the 1971 Committee (*1a*) and estimated the energy requirements from birth to 10 years from the observed intakes of healthy children growing normally.

6.3.1.1 *Infants (birth to 12 months).* Up to 6 months of age the 1971 Committee (*1a*) used the results collected by Fomon et al. (*55*) for the intakes of infants fed breast milk by bottle. For older children, they used figures for the intakes of children in the United States of America and the United Kingdom presented by Leitch & Widdowson to the second FAO Committee on Calorie Requirements (*56*). A much larger collection of information is now available on the intakes of infants, children, and adolescents compiled from studies in Canada, Sweden, UK, and USA (*57*). Results from developing countries were not included in this analysis to ensure that the intakes represent those of groups of children who, on average, were growing along the 50th centile of the WHO reference standard. For the first 12 months there are some 4000 data points available. The means of the measured intakes at each month for the first year are given in Table 21. That table shows a fall in energy intake per kg of body weight between 3 and 6 months which is maintained until 9 months, and then rises again towards 1 year. We believe this reduction to be a real phenomenon, representing a period when the very high growth rate characteristic of the first 3 months of life has declined but is not yet balanced by increased physical activity.

Table 21. Calculated energy requirements of infants from birth to 1 year

Age	Intake[a]		Calculated energy requirement[b]		Median body weight[c]		Total requirement			
							Boys		Girls	
(months)	(kcal$_{th}$/kg per day)	(kJ/kg per day)	(kcal$_{th}$/kg per day)	(kJ/kg per day)	Boys (kg)	Girls (kg)	(kcal$_{th}$/day)	(kJ/day)	(kcal$_{th}$/day)	(kJ/day)
0.5	118	494	124	519	3.8	3.6	470	1 965	445	1 860
1–2	114	477	116	485	4.75	4.35	550	2 300	505	2 115
2–3	107	448	109	456	5.6	5.05	610	2 550	545	2 280
3–4	101	423	103	431	6.35	5.7	655	2 740	590	2 470
4–5	96	402	99	414	7.0	6.35	695	2 910	630	2 635
5–6	93	389	96.5	404	7.55	6.95	730	3 055	670	2 800
6–7	91	381	95	397	8.05	7.55	765	3 220	720	3 010
7–8	90	377	94.5	395	8.55	7.95	810	3 390	750	3 140
8–9	90	377	95	397	9.0	8.4	855	3 580	800	3 350
9–10	91	381	99	414	9.35	8.75	925	3 870	865	3 620
10–11	93	389	100	418	9.7	9.05	970	4 060	905	3 790
11–12	97	406	104.5	437	10.05	9.35	1 050	4 395	975	4 080
12	102	427								

[a] Observed intakes at ages indicated, from data of Whitehead et al. (*57*), omitting studies 7 and F^b on technical grounds. Average intake predicted from equation (age in months): $I(\text{kcal}_{th}/\text{kg}) = 123 - 8.9\,\text{age} + 0.59\,\text{age}^2$.

[b] Requirement over interval indicated, calculated as predicted intake + 5% (see text).

[c] NCHS median weights at mid-point of month.

Table 22. Energy requirements of infants: comparison of present estimates with those of the 1971 Committee (*1a*)

Age (months)	Present	1971	Present	1971
	(kcal$_{th}$/kg)		(kJ/kg)	
0–3	116	120	485	500
3–6	99	115	415	480
6–9	95	110	400	460
9–12	101	105	420	440
Average during first year	103	112	430	470

The intakes of the breast-fed infants in these studies were measured by test-weighing. Recent measurements of breast-milk consumption by the deuterium oxide method suggest that test-weighing underestimates actual milk consumption by about 5% (*58*). Estimates of the intake of other foods are likely to have a similar bias. The Consultation therefore accepted that the estimates of the energy requirements of infants should be set at 5% above the average observed intakes. The figures that result are still 10–15% lower than those proposed by the 1971 Committee (*1a*) (Table 22).

6.3.1.2 *Children 1–10 years*. In order to calculate the energy requirements of children over 1 year of age from measurements of energy expenditure, both the time and cost of all types of physical activity need to be known. Unfortunately, this information is not available for children in this age group, and it is therefore necessary, as for infants, to evaluate their energy requirements from data on dietary intake. Table 23 shows the mean intakes of boys and girls from 1 to 10 years. These values are derived from a critical review of the recent literature,[1] and are based on studies in developed countries and in the more affluent groups of developing countries. The regression equations were calculated from 6500 data points for girls and 6000 for boys.

Table 23 shows that after 3–4 years the estimated intakes fall below the requirements for children proposed by the report of the 1971 Committee (*1a*). The meaning of this may be that physical activity, and thus the energy requirement of children, has declined in recent times, reflecting increasingly sedentary life-styles in the

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[1] Ferro-Luzzi, A. & Durnin, J.V.G.A. *The assessment of human energy intake and expenditure: a critical review of the recent literature*. Rome, FAO, 1981 (Document ESN: FAO/WHO/UNU/EPR/81/9).

large cities of industrialized countries. There is some evidence of this in older children (*60*). If true, such a reduction may well be considered undesirable from the point of view of optimal health and function, as maintenance of adequate levels of physical activity is thought to be necessary in the formative years of the growing child. Therefore the Consultation considered that recommendations for this age group should be based on observed intakes, but that they should be increased by 5% to allow for a desirable level of physical activity.

Little information is available in the literature on the energy intakes of children in the developing countries, who may be expected to lead a more active life, having to walk long distances, undertaking hard physical work, sometimes being less tied to sedentary activities by strict school schedules, etc. Their energy intakes are smaller than those of their counterparts of the same age in developed countries, but the difference largely disappears when the intakes are recalculated on a body-weight basis. One might postulate that in this case, externally imposed limitations may restrict both energy intakes and energy expenditure. The extra 5% added to observed intakes may be considered a realistic estimate of the requirement if enough energy is to be available for a desirable level of physical activity.

6.3.1.3 *Children 10–17 years.* After 10 years of age it becomes feasible to base requirements on estimates of energy expenditure built up by the factorial method. The approach is basically the same as for adults.

As in adults, the BMR in children is generally the largest component of the requirement. Because of differences in the timing of the pubertal growth spurt, both weights and heights at any given age are rather variable. For example, in 12-year-old boys, weight may vary from 28 kg (3rd centile) to 59 kg (97th centile), and height from 1.36 to 1.64 m. The best predictor of the BMR is weight and, as in adults, the BMR per kg varies with body weight. At any given weight, variations in height make no difference in boys and only a small difference in girls (at a given weight the predicted BMR changes by less than 5% as one moves from the median height to the 3rd or 97th centiles, Annex 1). As discussed in section 3.5.1, the BMR may be estimated either from the actual weight or from the median weight for height and age, as shown in Baldwin's table (Annex 2(B)). Values for the BMR of adolescents at median weight for height and age are given in Table 24.

Table 23. Estimated average daily energy intakes and requirements

Age	Boys					
	Intake[a]		Requirement			
			Present[b]		1971	
(years)	(kcal$_{th}$/day)	(MJ/day)	(kcal$_{th}$/day)	(MJ/day)	(kcal$_{th}$/day)	(MJ/day)
1–2	1 140	4.76	1 200	5.02	1 180	4.93
2–3	1 340	5.60	1 410	5.89	1 360	5.69
3–4	1 490	6.23	1 560	6.52	1 560	6.52
4–5	1 610	6.73	1 690	7.07	1 720	7.19
5–6	1 720	7.19	1 810	7.57	1 870	7.82
6–7	1 810	7.57	1 900	7.94	2 010	8.40
7–8	1 895	7.92	1 990	8.32	2 140	8.95
8–9	1 970	8.24	2 070	8.66	2 260	9.45
9–10	2 045	8.55	2 150	8.99	2 380	9.95

[a] From data of Ferro-Luzzi & Durnin (see footnote 1 on page 92).

[b] Intakes + 5% (see text).

[c] From NCHS median weights at mid-year.

Table 24. Basal metabolic rates of adolescent boys and girls

Age (years)	Height[a] (cm)	Weight[b] (kg)	BMR[c]			
			total		per kg	
			(kcal$_{th}$/day)	(MJ/day)	(kcal$_{th}$/day)	(MJ/day)
Boys						
10–11	140	32.2	1 215	5.08	37.7	0.16
11–12	147	37.0	1 300	5.43	35.1	0.15
12–13	153	40.9	1 370	5.73	33.4	0.14
13–14	160	47.0	1 465	6.12	31.4	0.13
14–15	166	52.6	1 570	6.57	29.9	0.12
15–16	171	58.0	1 665	6.96	28.7	0.12
16–17	175	62.7	1 750	7.32	27.9	0.12
17–18	177	65.0	1 790	7.48	27.5	0.12
Girls						
10–11	142	33.7	1 160	4.85	34.3	0.14
11–12	148	38.7	1 220	5.10	31.5	0.13
12–13	155	44.0	1 280	5.38	29.1	0.12
13–14	159	48.8	1 340	5.60	27.5	0.12
14–15	161	51.4	1 375	5.75	26.7	0.11
15–16	162	53.0	1 395	5.83	26.3	0.11
16–17	163	54.0	1 405	5.87	26.0	0.11
17–18	164	54.4	1 410	5.89	25.9	0.11

[a] Median height for age from NCHS standards.

[b] Median weight for height and age from Baldwin's standards (Annex 2(B)).

[c] Boys: BMR = $17.5W + 651$ kcal$_{th}$/day (2.72 MJ/day). Girls: BMR = $12.2W + 746$ kcal$_{th}$/day (3.12 MJ/day).

of children aged 1–10 years, compared with estimates of 1971 Committee (*1a*)

Girls						Requirement by weight[c]			
Intake[a]		Requirement				Boys		Girls	
		Present[b]		1971					
(kcal$_{th}$/ day)	(MJ/day)	(kcal$_{th}$/ day)	(MJ/day)	(kcal$_{th}$/ day)	(MJ/day)	(kcal$_{th}$/kg per day)	(kJ/kg per day)	(kcal$_{th}$/ kg per day)	(kJ/kg per day)
1 090	4.56	1 140	4.76	1 180	4.93	104	435	108	452
1 250	5.23	1 310	5.48	1 350	5.64	104	410	102	427
1 370	5.73	1 440	6.02	1 520	6.35	99	414	95	397
1 465	6.12	1 540	6.44	1 670	6.98	95	397	92	385
1 550	6.48	1 630	6.81	1 790	7.48	92	385	88	368
1 620	6.77	1 700	7.11	1 900	7.94	88	368	83	347
1 685	7.05	1 770	7.40	2 010	8.40	83	347	76	318
1 740	7.28	1 830	7.65	2 110	8.82	77	322	69	268
1 795	7.51	1 880	7.86	2 110	8.82	72	301	62	259

For growth, an addition of 5 kcal$_{th}$ (21 kJ) per g is allowed for the average daily cost of weight gain (*61*). It is recognized that growth does not occur at a regular rate from day to day (section 3.2). However, even during the pubertal spurt the requirement for growth is so small compared with the total energy requirement that no extra allowance in the energy intake need be made for this variability.

In order to illustrate quantitatively the energy requirements for different patterns of activity, an attempt was made to identify the time that might be spent by each sex and age group sleeping, going to school (including homework), and undertaking light, moderate, and heavy physical activity. There is little information in the literature on the amount of time children and adolescents spend on different types of activity, but these are bound to be highly variable. The time allocations were estimated as the daily means throughout the year, assuming that the average child still goes to school at the age of 10. It was also assumed that the child begins secondary school at the age of 13. In societies where children begin work rather than go to secondary school, patterns of activity should be calculated accordingly.

The values shown in Table 25 represent the best estimates of levels of activity at different ages that would be compatible with a good rate of growth and optimal development and health in children of appropriate weight and height for their age.

In calculating energy expenditure, it has been assumed that the energy cost of sleep is equal to the BMR. Estimates of the additional energy costs of other activities, over and above the BMR, were based upon the principles described in section 4. The gross energy costs were assessed as follows in terms of BMR units:

	Boys	*Girls*
Going to school and light activity	1.6 BMR	1.5 BMR
Moderate activity	2.5 BMR	2.2 BMR
High activity	6.0 BMR	6.0 BMR

The somewhat lower values given for girls assume that their intensity of activity would decline to the level found in adult women (see section 6.2).

Table 26 shows an example of how energy expenditure was calculated from timed activities of a 10½-year-old boy in a developing country. Table 27 shows a similar but less detailed calculation for a girl in an industrialized country. The calculations for both sexes and for ages 10–17 years are shown in Annex 7. Table 28 shows, for each age group, values for energy needs based in this way on an estimate of energy expenditure plus the increment for growth, together with the relationship to BMR. The BMR factor varies over a rather narrow range, from about 1.6 to 1.75 in boys and from 1.5 to 1.65 in girls.

The new estimates of energy requirements, based on calculated energy expenditure, are compared in the table with observed energy intakes of adolescents. The 1971 Committee's recommendations (*1a*) are also shown to serve as a reference. It is obvious that the new estimates are appreciably and consistently lower than those proposed by that Committee and that the observed values of energy

Table 25. Estimated time allocation (hours per day) used in the calculation of energy requirements of adolescents

Age (years)	Sleep	School[a]	Activity: Light	Activity: Moderate	Activity: High
10–11	9	4	4	6.5	0.5
11–12	9	5	4	5.5	0.5
12–13	9	5	5	4.5	0.5
13–14	9	5	6	3.5	0.5
14–15	8	6	7	2.5	0.5
15–16	8	6	7	2.5	0.5
16–17	8	6	7	2.5	0.5
17–18	8	6	7	2.5	0.5

[a] Average over whole year.

Table 26. Example of the calculation of the daily energy expenditure of a 10½-year-old boy in a developing country (body weight = 32.2 kg)

Activity	hours	kcal$_{th}$	kJ
Sleep at 1.0 × BMR[a]	9	455	1 900
School at 1.6 × BMR	2.5	200	840
Light activity at 1.6 × BMR:			
sitting, standing, moving around	6.5	525	2 200
social activities, washing, play	2	160	670
Moderate activity at 2.5 × BMR:			
walking, household tasks, agricultural tasks, play	3	380	1 590
Heavy activity at 6.0 × BMR:			
fetching wood and water, agricultural tasks	1	300	1 260
Growth		60	250
Total requirement per 24 hours = 1.71 × BMR		2 080	8 710

[a] BMR estimated to be 1215 kcal$_{th}$/day (5080 kJ/day).

Table 27. Example of the calculation used to derive energy expenditure in a 10-year-old girl (body weight = 33.8 kg)

Activity	hours	kcal$_{th}$	kJ
Sleep at 1.0 × BMR[a]	9	435	1 820
School at 1.5 × BMR	4	290	1 210
Light activity at 1.5 × BMR	4	290	1 210
Moderate activity at 2.2 × BMR	6.5	690	2 890
High activity at 6.0 × BMR	0.5	145	610
Total expenditure		1 850	7 740
Growth		65	270
Total requirement per 24 hours = 1.65 × BMR		1 915	8 010

[a] BMR estimated to be 1160 kcal$_{th}$/day (4850 kJ/day).

intakes are lower still. Between 10 and 18 years the new estimates of energy requirements of boys exceed the actual figures of observed energy intakes by an amount that corresponds almost exactly with the amount of energy thought desirable for children to spend in high activity (½ hour at 6.0 × BMR). In girls the discrepancy is greater, presumably reflecting a low level of physical activity in the sample whose intakes were measured. The Consultation considered that the estimated requirements for this age group should not be decreased to match the observed intakes in affluent countries. Fulfilment of the requirements as proposed is likely to be beneficial if physical activity is increased, and in developing countries will provide a margin of safety.

Table 28. Comparison of calculated average energy expenditure, observed intakes, and recommendations of 1971 Committee for adolescents aged 10–18 years

Age	Expenditure	Expenditure		Intake[b]		1971 Committee[c] recommended requirement	
(years)	(× BMR)[a]	($kcal_{th}$/day)	(MJ/day)	($kcal_{th}$/day)	(MJ/day)	($kcal_{th}$/day)	(MJ/day)
Boys							
10–11	1.76	2 140	8.95	2 110	8.82	2 500	10.46
11–12	1.73	2 240	9.37	2 170	9.07	2 600	10.87
12–13	1.69	2 310	9.66	2 200	9.20	2 700	11.29
13–14	1.67	2 440	10.20	2 280	9.53	2 800	11.71
14–15	1.65	2 590	10.83	2 340	9.79	2 900	12.13
15–16	1.62	2 700	11.29	2 390	9.99	3 000	12.55
16–17	1.60	2 800	11.71	2 440	10.20	3 050	12.76
17–18	1.60	2 870	12.0	2 490	10.41	3 100	12.97
Girls							
10–11	1.65	1 910	7.99	1 850	7.74	2 300	9.62
11–12	1.63	1 980	8.28	1 890	7.90	2 350	9.83
12–13	1.60	2 050	8.57	1 930	8.07	2 400	10.04
13–14	1.58	2 120	8.87	1 970	8.24	2 450	10.25
14–15	1.57	2 160	9.03	2 010	8.40	2 500	10.46
15–16	1.54	2 140	8.95	2 050	8.57	2 500	10.46
16–17	1.53	2 130	8.91	2 080	8.70	2 420	10.12
17–18	1.52	2 140	8.95	2 120	8.87	2 340	9.79

[a] Expenditure calculated as in Tables 26 and 27 and Annex 7. BMR from equations in Table 5.
[b] Intakes from reference (*62*).
[c] Reference (*1a*).

6.3.2 *Protein requirements*

6.3.2.1 *Infants from birth to 6 months.* As in the case of energy, the 1971 Committee based its estimate of the protein requirements from birth to 6 months on intake data because of the difficulties of accurately allowing for growth and maturation. Many observations show that infants breast-fed by healthy well nourished mothers (*62–65*) or fed breast milk by bottle (*55*) can grow at a satisfactory rate for 4–6 months using the standards adopted in this report. It may therefore be concluded that for the first 6 months of life the protein needs of an infant will be met if its energy needs are met and the food providing the energy contains protein in quantity and quality equivalent to that of breast milk.

The average protein content of human milk, calculated as total N × 6.25, has been taken as 1.15 g per 100 ml after the first month

Table 29. Average intake of protein by breast-fed infants aged 0–4 months

Age (months)	Breast milk consumed[a] (ml)	Protein intake[a] (g/day)	Weight[b] (kg)	Average protein intake (g/kg per day)	Average, 1971 Committee[c] (g/kg per day)
Boys					
0–1	719	9.35	3.8	2.46	2.40
1–2	795	9.15	4.75	1.93	1.91
2–3	848	9.75	5.6	1.74	1.71
3–4	822	9.45	6.35	1.49	1.64
Girls					
0–1	661	8.6	3.6	2.39	
1–2	731	8.4	4.35	1.93	
2–3	780	9.0	5.05	1.78	
3–4	756	8.7	5.7	1.53	

[a] From Table 20. In accordance with the findings of Wallgren (*69*) and Whitehead (*63*), the breast-milk consumption by female infants is taken as 8% less than that of male infants.

[b] NCHS median, mid-point of months.

[c] From reference (*1a*), Table 15 (data of Fomon).

of lactation[1]. It is recognized that human milk contains about 40 mg of non-amino nitrogen per 100 ml (approximately 20% of total N) (*66, 68*) but, following the usual convention, we have assumed that this nitrogen fraction is utilized. If the average energy content is taken as 70 kcal_{th} (290 kJ) per 100 ml, the protein content is 1.64 g per 100 kcal_{th} (6.85 g per MJ).

An estimate of the average protein intake per kg in breast-fed infants up to 4 months is shown in Table 29. Although the amount of milk consumed by infant girls is less than that by boys, on a body-weight basis the intakes are virtually the same. For comparison, the table also shows the average protein intakes of infants who were fed breast milk by bottle (*55*). These were the data on which the 1971 Committee based its estimates of protein requirements for infants up to 6 months old.

Estimates of the protein intake of breast-fed infants are not shown after the age of 4 months, because from this age there is insufficient information on the intakes of exclusively breast-fed infants who are growing satisfactorily. It may be noted that if the estimates of energy requirements shown in Table 21 are correct, it would need 1040 ml of breast milk to fulfil the energy needs of a male

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[1] The values adopted, 1.15 g of total N and 70 kcal_{th} (290 kJ) per 100 ml of human milk are based on the compilations of Macy (*66*), the Department of Health and Social Security, United Kingdom (*52*), and the WHO Collaborative Study on Breast-feeding (*67*).

infant at 5–6 months. This volume is larger than has usually been observed.

For the purpose of comparison with older infants, it may be noted that if the average daily energy intake at 6 months is 95 kcal_{th} (400 kJ) per kg (Table 22), the corresponding average protein intake from breast milk will be 1.56 g per kg per day.

6.3.2.2 *Children from 6 months onwards.* The period from 6 to 12 months is clearly the most critical, because of rapid growth during this time and because the child increasingly relies on supplementary foods. The first priority must therefore be to establish as reliable an estimate as possible of the safe level of protein intake for children of this age. One can then with some confidence interpolate the safe level for older children from this estimate.

The protein requirements of children have been calculated in the first instance by a modified factorial method. As with adults, and with the same limitations, the maintenance requirements can in principle be estimated from measurements of nitrogen balance at several levels of intake. There is the additional problem of determining an appropriate value for the N retained during growth and the requirement for achieving this retention.

(*a*) *Maintenance requirement.* Several short-term N-balance studies have been carried out in older infants and young children to determine the protein requirement by the slope–ratio method (see section 5). These have been healthy children, usually recovered from malnutrition, short in stature but in the normal range of weight for height. The usual design follows that of adult studies: energy intake is kept constant at a level assumed to be adequate and protein is given at different levels, each for a period of several days. From these studies it is possible to calculate a maintenance requirement (no growth, N equilibrium) from the regression of N balance on N intake, allowing 10 mg of N per kg per day for sweat and miscellaneous N losses. In theory it is also possible from these studies to determine the amount of protein needed in the diet to meet any chosen value for N retention.

The results in Table 30 indicate that in the critical age group from 6 to 20 months, with milk as a source of protein, the average maintenance requirement is approximately 115–120 mg of N per kg per day. Studies of a different design, in which N balance was measured only once or twice in each child over a range of intakes, gave a maintenance requirement of 110 mg of N per kg per day (*75*).

Table 30. Results of several short-term balance studies[a] on young children of different ages

	6–20 months			17–31 months		38–62 months		
	1[a]	2[a]	3[a]	4[a]	5[a]	6[a]	7[a]	8[a]
Protein source	Milk	Egg	Milk	Soy	Rice, fish	Milk	Soy	Mixed
No. of children	24	10	10	10	7	7	7	3
Intake range (/kg/day)								
– Energy ($kcal_{th}$)	61–92	69–88	100	100	110	100	100	100
(kJ)	255–385	290–370	420	420	460	420	420	420
– N (mg)	16–173	71–150	80–320	80–320	120–320	120–240	120–240	160–320
Slope	0.69	0.71	0.74	0.61	0.54	0.53	0.51	0.44
Average maintenance requirement[b] (mg N/kg per day)	117	120	80	98	130	91	137	164
Corrected for digestibility[c]	117	117	80	97	98	91	100	118

[a] Column 1 = reference (*70*); column 2 = reference (*70*); column 3 = reference (*71*); column 4 = reference (*71*); column 5 = reference (*72*); column 6 = reference (*73*); column 7 = reference (*73*); column 8 = reference (*74*).

[b] Allowing 10 mg of N/kg for skin losses.

[c] Corrected for digestibility of milk, where appropriate.

The results of the balance studies in the older age groups are somewhat variable. The estimated maintenance requirement, corrected to the digestibility of cow's milk, ranged from 80 to 118 mg of N per kg per day. Since the average maintenance requirement in young adults studied in short-term balances was estimated at 98 mg of N per kg per day (section 6.1.2), it seems reasonable, for intermediate age groups, to interpolate between two well-established values. These, rounded off, would be 120 mg of N per kg per day at 1 year, falling to 100 mg of N per kg per day at 20 years.

In the balance measurements on children the range of inter-individual variation in the estimate of the maintenance requirement was similar to that found in the much more numerous short-term balances in adults, and the Consultation has therefore accepted the same value of 12.5% for the coefficient of variation of the maintenance requirement.

It is assumed that this represents variability in the efficiency of utilization—an assumption that is important when the requirement for growth is being considered.

(*b*) *The requirement for growth.* The mean rate of N accretion during growth can be estimated from the expected daily rate of weight gain (NCHS 50th centile) and the N concentration in the body. This is low at birth, and increases to the adult value by 5 years of age or earlier. The extent of the increase is important between 6 and 12 months, when growth is rapid. The 1971 Committee (*1a*) reported values for body N concentration at different ages obtained by three different methods. At some ages the values were not in good agreement.

More recent estimates of N accretion during growth have been provided by Fomon et al. (*76*). They are similar to those accepted by the 1971 Committee (*1a*, Table 12) but lower than some earlier estimates (*77*).

However, as pointed out in section 3.2.1, it should not be assumed that growth always proceeds at exactly the same rate from day to day, even in apparently healthy children. The cause, extent, and significance of these fluctuations in growth rate are difficult to assess. Table 31 illustrates the extent of variation in weight gain that has been observed over a period of 4 weeks in healthy children aged 4–6 months (*78;* and S.J. Fomon, personal communication).

Table 31. Variability of weight gain and energy intake (expressed as average daily rates) over one month intervals in boys aged 3½–6½ months[*]

	Period (days of age)		
	112–140	140–168	168–196
Weight gain (g/day)			
10th centile	9.8	9.0	5.0
50th centile	17.5	17.6	14.8
90th centile	25.8	25.3	20.8
mean	17.7	17.6	14.1
SD	6.9	7.1	6.4
CV (%)	39	40	45
Weight gain g/100 kcal$_{\text{th}}$ (g/1000 kJ)			
10th centile	1.7 (4.1)	1.3 (3.1)	0.8 (1.9)
50th centile	2.5 (6.0)	2.5 (6.0)	2.1 (50.2)
90th centile	3.8 (9.1)	3.4 (8.1)	3.0 (7.1)
mean	2.6 (6.2)	2.4 (5.7)	2.0 (4.8)
SD	1.0 (2.4)	1.0 (2.4)	0.9 (2.2)
CV (%)	38 (90.8)	42 (100)	45 (107.6)
Energy intake kcal$_{\text{th}}$*/day* (kJ/day)			
10th centile	78 (326)	74 (310)	72 (301)
50th centile	95 (397)	95 (398)	89 (372)
90th centile	115 (481)	114 (477)	109 (456)
mean	96 (402)	96 (407)	90 (377)
SD	14 (59)	15 (63)	15 (63)
CV (%)	15 (63)	16 (67)	17 (71)

[*] Unpublished data of Fomon.

The variability of gain is much greater than the variability of intake, so that presumably it results to a large extent from variation in the efficiency of utilization of food for growth.

Longitudinal studies in Jamaica on reasonably healthy and well nourished children showed that over successive months a period of faltering would usually be followed by a period of weight gain at 2–3 times the normal rate (*79*). Very little is known about variations over shorter periods. Daily measurements of children's weights even under standardized conditions in a metabolic ward show fluctuations, which no doubt resulted partly from differences in the amounts of urine and stool retained at the moment of weighing.

They may also represent differences from day to day in the proportions of fat and lean tissue laid down. It is known that individual children, at least when recovering from malnutrition, may differ widely in the composition of weight gain (*80*).

If it is accepted that different amounts of protein may be laid down from day to day, as part of the normal process of growth, the question then arises, what is the effect of this on the child's *daily* protein requirement? In order to maintain a satisfactory overall rate of growth, any failure to lay down protein on one day must be compensated for on a subsequent day. Studies such as those cited in section 5 suggest that the body has a very limited capacity for storing amino acids or for drawing on the free amino acid pool for protein synthesis. Even during short periods such as 12 hours without food, nitrogen balance becomes negative (*81*). Therefore, in accordance with classical teaching, it seems very unlikely that amino acids provided on a day when there was no growth could be held "in stock" to be utilized for growth later on. It follows that since it is impossible to foretell on which days the growth rate will be low or high, it is necessary to provide enough every day for a possible extra demand.

There is no evidence available on which to base a realistic estimate of the extra requirement for protein that might arise in this way. In this situation a judgement has to be made. A reasonable judgement must lead to estimates that are similar to values established independently, such as the intakes of healthy breast-fed children. It was found that if, in the factorial calculation the growth component of the protein requirement is set at 50% above that based on the theoretical daily amount of N laid down, the calculated average requirement at 4 months comes close to the average intake of breast-fed infants (Table 32). To provide a physiological margin of safety,

Table 32. Average protein requirements of infants calculated by the factorial method, compared with average intakes from breast milk[a]

Age (months)	N increment[b]	N increment[c] × 1.5	Corrected for efficiency[d]	Maintenance[e]	Total	Total as protein	Intake from breast milk[f]
	(mg N/kg per day)					(g protein/kg per day)	
1–2	112	168	240	120	360	2.25	1.93
2–3	80	120	171	120	291	1.82	1.74
3–4	55	81	116	120	236	1.47	1.49
4–5	44	66	94	120	214	1.34	–
5–6	41	62	89	120	209	1.30	–
6–9	37	56	80	120	200	1.25	–
9–12	30	45	64	120	184	1.15	–

[a] Although body weights differ between male and female infants, it is not considered that requirements per kg will differ.

[b] From reference (*76*).

[c] See text.

[d] Efficiency of utilization assumed to be 70%.

[e] See text.

[f] From Table 29.

it was therefore decided to increase the theoretical growth requirement by a factor of 50%.

The amount of dietary nitrogen needed to allow for a given amount of N deposited can be derived from the same slope as the requirement for maintenance. It is assumed that dietary protein is used with the same efficiency for growth as it is for maintenance, and on theoretical grounds there is no reason to suppose that this assumption is not valid (section 5.4). The appropriate slope for diets based on milk or egg has been taken as 0.7 at all ages.

Table 32 shows the detailed calculation of the average requirement of protein for infants up to 1 year, over the period when growth makes a significant contribution. Although the factorial method is not, in fact, used for infants below the age of 6 months, the calculations have been made in order to compare the results with the estimated protein intakes from breast milk (Table 29). This comparison suggests that the proposed addition of 50% to the nitrogen increment does not unrealistically increase the estimate, and it may even be too small. This is a subject on which more research is urgently needed.

Finally, a correction has to be made for the inter-individual variability of growth, in order to arrive at a safe level of protein intake for virtually all healthy children. The coefficients of variation shown in Table 31 represent a mixture of inter- and intra-individual variability over periods of 4 weeks. This interval should be long enough to smooth out the effects of day-to-day fluctuations in the growth of each individual child, as discussed above. It is apparent that over a period of a month children do vary in their *average* daily rate of growth, with a CV of approximately 37%. The CV will be lower over longer periods and higher over shorter periods. If the one-month CV is accepted as a reasonable compromise, an overall CV can be calculated, as shown in the footnote to Table 33. This is 15% at 6–9 months, falling to 12.5% in the second year. The data do not justify more detailed estimates.

It is apparent that, at present, we do not have an adequate theoretical basis for calculating the variability of the protein requirement for growth in young children, a major problem being that this variability depends on the length of the period over which the growth is measured. It is hoped that this discussion of the problem will stimulate further research.

The estimated safe levels calculated in this way are shown for children in Table 33, and for adolescents in Table 34, and compared with those of the 1971 Committee (*1a*). In adolescents the requirements per kg have to be given separately for the two sexes, because of differences in the timing of the growth spurt. In younger

Table 33. Safe level of protein intake (milk or egg protein) of infants and children up to 10 years of age (sexes combined)

Age (years)	Maintenance[a]	Growth[b]	Total	+2 SD[c]	CV%	Safe level	1971 Committee[d]
	(mg N/kg per day)					(g protein/kg per day)	
0.25–0.5	120	100	220	297	17.5	1.86	–
0.5–0.75	120	80	200	264	16	1.65	1.62
0.75–1	120	64	184	237	14.5	1.48	1.44
1–1.5	119	41	160	202	13	1.26	1.23
1.5–2	119	31	150	187	12.5	1.17	
2–3	118	28	146	181	12	1.13	1.15
3–4	117	24	141	175	12	1.09	1.09
4–5	116	21	137	170	12	1.06	1.03
5–6	115	17	132	164	12	1.02	1.00
6–7	114	17	131	163	12	1.01	0.95
7–8	113	17	130	162	12	1.01	0.90
8–9	112	17	129	161	12	1.01	0.86
9–10	111	17	128	155	12	0.99	0.83

[a] See text.

[b] After the addition of 50% to theoretical increment, and correction for 70% efficiency of utilization (see Table 32).

[c] CV for maintenance taken as 12.5%; CV for growth taken as 35%. Combined CV (CV_{total}) calculated as:

$$CV_{total} = \sqrt{(M \times CV_{maintenance})^2 + (G \times CV_{growth})^2}/(M + G).$$

[d] Reference (*1a*).

Table 34. Safe level of protein intake for adolescent girls and boys (10–18 years)

Age (years)	Maintenance	Growth	Total	+2 SD	Safe level	1971 Committee
	(mg N/kg per day)				(g protein/kg per day)	
Girls						
10–11	110	19	129	161	1.00	0.78
11–12	109	17	126	157	0.98	0.75
12–13	108	15	123	154	0.96	0.71
13–14	107	13	120	150	0.94	0.65
14–15	106	9	115	144	0.90	0.60
15–16	105	7	112	140	0.87	0.58
16–17	104	2	106	132	0.83	0.57
17–18	103	0	103	129	0.80	–
Boys						
10–11	110	17	127	159	0.99	0.82
11–12	109	17	126	157	0.98	0.80
12–13	108	21	129	161	1.00	0.78
13–14	107	17	124	155	0.97	0.75
14–15	106	17	123	154	0.96	0.70
15–16	105	13	118	147	0.92	0.65
16–17	104	11	115	144	0.90	0.63
17–18	103	7	110	137	0.86	–

Calculations and notes as for Table 33.

children there is little difference from the earlier figures, although the ways in which the values have been derived are different. From 6 years onwards the present estimates are somewhat higher than the earlier ones. This reflects the higher current estimate for adults, since the maintenance requirement has been calculated by linear interpolation between infants and adults. Much of the difference disappears when revised corrections are made for protein score and digestibility (section 7.3).

The growth component in Table 32 has been derived from theoretical values for N increment, whereas nearly all balance studies in children on usual intakes, many of which were well above the requirement, have shown that they retain more than the theoretical amounts of N (*82–84*). Although these studies differ in type of subject and amount and kind of protein, they agree in showing apparent N balances greater than those expected from measurements of body composition in man or carcass nitrogen in animal experiments.

The discrepancies between observed and expected balance are smallest when N retention is high, such as in infants and also in children during catch-up growth (*75*). They are largest when intakes are high and retention is expected to be low, such as in older children during normal growth. This suggests an inherent problem of methodology. It is well known that the errors of the N balance method summate to exaggerate the apparent retention (*85*).[1]

Longer-term balances. As emphasized earlier (section 5), although short-term N-balance studies provide valuable information, the conditions are artificial and the conclusions drawn depend heavily on a series of largely unverified assumptions. Long-term studies during which children grow normally would clearly inspire much greater confidence regarding the adequacy of the diets fed. Details of the few available long-term balances at a single level of protein intake are shown in Table 35. The diets fed in these long-term studies were controlled at a fixed level and were composed of foods commonly eaten by poor people in the countries represented. All except the oldest group were poor children and most had a previous history of malnutrition and stunting. Some were parasitized and all had minor febrile and afebrile illnesses during the studies. The weight gain was in general satisfactory, but some children did not gain weight at the expected rates at some periods. It is therefore questionable whether the diets fed should be thought of as meeting average requirements or constituting a safe level for groups of children growing at individually variable rates, including short intervals of little or no gain.

Interpretation of the long-term balance figures is difficult in view of the different age ranges covered by the various studies.

In the long-term balance study on children aged 8–12 months (Table 35, study A) an intake of 1.35 g of protein per kg per day (after correction to the digestibility of cow's milk) supported satisfactory growth in almost all of the children for most of the time, but not in all the children at all times. It may, therefore, be reasonable to consider this as an average requirement for children at this age under the conditions of the study. This value is 8% higher

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[1] An alternative approach examined by the Consultation was to estimate the protein requirement from the basal metabolic rate—a procedure analogous in principle to the use by the 1971 Committee of the factor 2 mg N per basal kcal to estimate the maintenance requirement. Since reliable estimates of the maintenance requirement have now been obtained from N-balance measurements, calculation from the BMR would only be useful to provide values for the total requirement. However, the BMR per kg changes little between 6 months of age and 3 years (Table 5), whereas the growth rate rapidly falls off. Thus changes in BMR with age in no way reflect the changes in growth rate, and hence in protein requirement, that occur in infancy and to a lesser extent in puberty. This approach, therefore, cannot be considered useful.

Table 35. Results of long-term nitrogen balance studies in children

	Study A (ref. *86*)	Study B (ref. *87*)	Study C (ref. *83*)	Study D (ref. *84*)	Study E (ref. *88*)	Study F (ref. *88*)
Age ($\bar{x}$)	8–12(10) months	22–40(30) months	29–46(30) months	2–5 years	7–9 years[a]	
No. of subjects, sex	6 M	6 M	11 M	20 F+M	13 F	6 F
Duration of study (days)	90	120	77	180	48	42
Weight gain (g/day)	9.4[b]	11[c]	7.2±8.2[d]	–[e]	NA	NA
Protein source	rice:fish 70:30	95% beans + corn 5% veg.	82% beans + corn + veg. 18% animal	wheat or rice + veg.	mixed, 45% animal	all vegetable
Intake/kg per day						
energy, kcal$_{th}$ ($\bar{x}$)	88–93(90)	82–91(86)	79–93(85)	100	78	80
energy, kJ ($\bar{x}$)	368–389(376)	343–380(360)	331–389(356)	418	326	335
protein, g	1.76	1.73	1.85	2	0.80	1.39
Apparent digestibility (%)[f]	73	59±9	72±5	66	80	77
Protein intake corrected to digestibility of cow's milk (g/kg)	1.35	1.07	1.40	1.39	0.67	1.14
Crude N balance[g] (mg/kg per day)	71–100	68±7	90±22	100	25(13–43)	28(13–42)

[a] Data for diets 8 and 11–12 of the published study (*88*).

[b] 1 child did not gain weight at an adequate rate.

[c] 4 children had intestinal parasites and all had mild upper respiratory tract infections during the study. All children gained weight and 3 showed catch-up linear growth.

[d] 4 children had febrile infections during the study, 5 had other afebrile illness, and a few vomited occasionally. 1 child did not gain weight and 2 gained at less than the expected rate. 5 children had normal linear growth and 1 showed catch-up growth.

[e] Children described as healthy and growing according to US standards.

[f] $\frac{\text{Intake–faecal N}}{\text{Intake}} \times 100.$

[g] Intake – faecal N – urinary N.

than the average requirement of 1.25 g per kg per day at 6–9 months derived by the factorial method (Table 32). Addition of 2 SD (CV 12.5%) would give a safe level of 1.75 g of protein per kg per day. This may be regarded as a realistic estimate of the safe level of protein intake for children of 6–9 months in a developing country where the child is exposed to infections and perhaps periodic shortages of food. Under these conditions, it may be wise to adopt an estimate of the safe level of protein intake that has been derived from studies carried out in a comparable situation. The question of the additional demands imposed by these stresses is discussed in more detail in section 9.

In the long-term studies on preschool children the diets fed included a large proportion of plant food, so that digestibility was below that recorded for diets based on milk and eggs. Once the factor of digestibility is taken into account, the amount of protein that appears to support expected growth rates of 2–5-year-old children in the long-term studies (Table 35, studies B, C, and D) does not differ markedly from the requirement of high-quality protein predicted from the short-term studies. This observation indicates that the amino acid composition of practical diets is not necessarily a limiting factor for preschool children when consumed in the proportions used in the long-term studies. However, the habitual home diets of some populations may provide the same foods in different proportions, and their constituent proteins may not supply an adequate combination of essential amino acids. Under these circumstances the poor protein quality may require higher intakes. The margin of safety is obviously less for children than for adults, and the range of national diets needs to be examined with respect to amino acid content as well as digestibility, before concluding that no further adjustment for these factors is needed. How this is to be done is shown in section 7.3.

Long-term balance studies provide little information that might allow a firm estimate to be made of the safe levels of intake of school-age children and adolescents. A sample of data from studies of 7–9-year-old girls is included in Table 35 (studies E and F).

In the United States of America a single study of 14–15-year-old boys (*89*) indicated that an intake of 100–120 mg N per kg per day from a mixed diet was needed to produce consistently positive N balances. This represents an average intake, not corrected for digestibility, of 0.62–0.75 g of protein per kg per day in boys towards the end of the pubertal growth spurt.

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