Editor's Note:

This manuscript was accepted for publication in *The American Journal of Clinical Nutrition* on November 25, 1986, but not published because of the controversy at that time over the 1985 RDA Committee report. Now that the RDA report has been officially released, *AJCN* believes that this manuscript deserves separate publication.

Protein requirements in humans¹,²

Peter L Pellett

**ABSTRACT** The general principles underlying protein requirements are outlined and daily allowances for protein are derived appropriate to the various age and sex population subgroups of the United States. Median body weights are however used for all age groups of the population rather than the desirable body weights used previously for adults. Following the recommendations of the FAO/WHO/UNU international working group, the protein requirement for male and female adults was taken as 0.6 g·kg⁻¹·d⁻¹ of high-quality highly digestible protein. By use of an age-specific scoring system and the mean amino acid composition and digestibility of the US diet, this allowance became 0.83 g·kg⁻¹·d⁻¹ of mixed US dietary protein—a value similar to the previous RDA but derived in a different manner. Tabulated daily protein allowance data are presented for reference age and sex groups for the US population (child–adult) together with the additional needs of pregnancy and lactation. *Am J Clin Nutr* 1990;51:723–37.

**KEY WORDS** Protein requirement, protein allowance

**Introduction**

Food proteins provide amino acids for the synthesis of body protein and other important nitrogen-containing compounds, such as peptide hormones and neurotransmitters. The requirement for protein is thus a requirement for amino acids. The body is in a dynamic state; its proteins and other nitrogenous compounds are being degraded and resynthesized continuously. Several times more protein is turned over daily within the body than is ordinarily consumed, indicating that reutilization of amino acids is a major feature of the economy of protein metabolism (1). Because this process of recapacit is not completely efficient and some amino acids are lost by oxidative catabolism, there is a requirement for dietary nitrogen and nutritionally essential (indispensable) amino acids. Metabolic products of amino acids (urea, creatinine, uric acid, and other nitrogenous products) are excreted in the urine; nitrogen is also lost in feces, sweat, and other body secretions and excretions and in sloughed skin, hair, and nails. A continuous supply of dietary amino acids is required to replace these losses even after growth has ceased. Amino acids consumed in excess of the amounts needed for the synthesis of nitrogenous tissue constituents are not stored but are degraded; the nitrogen is excreted as urea and the keto acids remaining after removal of the amino groups are either utilized directly as sources of energy or are converted to carbohydrate or fat.

Nine amino acids—histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine—are not synthesized in adequate amounts by mammals and are, therefore, indispensable nutrients for humans. These are commonly called the essential amino acids. Arginine is synthesized by mammals but not in amounts sufficient to meet the needs of the young of most species; however, it is not required by the human infant for normal growth (2). When present in small amounts relative to other amino acids, such as in intravenous solutions of amino acid mixtures, it may limit protein synthesis (3). Although histidine is an essential amino acid for infants (2), it was not believed essential for adults (4) until recently, when several reports confirmed that dietary histidine is also required by the adult (5–8). Under special circumstances (eg, liver damage), amino acids such as cystine and tyrosine that are not normally essential may become so because of impaired conversion from their precursors, which are methionine and phenylalanine, respectively (9).

For establishing the requirement for protein, there are two well-established reference groups for which information can be regarded as reasonably reliable. These are young children and young male adults. For other age groups much less direct information than desirable is available, and protein needs must be assessed largely by interpolation or by extrapolation based on reasonable biological principles. In children and pregnant or lactating women, the protein requirement includes the needs associated with the deposition of tissues or secretion of milk at rates consistent with good health.

If more protein is ingested than is needed for metabolic purposes, essentially all the excess is metabolized and the nitrogen-containing end products are excreted. This occurs because protein is not stored in the body as a reserve, such as lipid in adipose tissue. Again in contrast to energy, no detrimental effect has been associated with protein intakes moderately above the actual requirement. For an individual, therefore, there is a wide range between intake just sufficient to compen-

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Received December 22, 1986.
Accepted for publication December 23, 1986.
sate for losses or to permit growth and intakes that may be associated with harmful effects. A person’s requirement for protein is the lower end of this range. For a group of similar persons, safe intake is considered to be an amount that will meet or exceed the requirements of practically all members of the group, allowing for individual variations. This safe amount was defined by two international groups (10, 11) on the basis of experimental data on individual variations as the average requirement plus two standard deviations.

Because the human body can adapt to low intakes of nitrogen, value judgments must be made about the state of protein nutriment that is considered desirable to achieve. Body size is the major determinant of the absolute requirements for protein. For children except for young infants, the protein required for growth is relatively small compared with that needed for maintenance. Nevertheless, satisfactory growth is a sensitive indicator of protein nutrition status.

### General principles for estimating protein requirements

When growth is occurring, there is not only net deposition of protein but also increased rates of both synthesis and breakdown. At submaintenance protein intakes, a diminished turnover of tissue protein is accompanied by a reduced catabolic rate for the amino acids liberated by protein breakdown (1, 12). In this way the tissue protein pool can, within limits, enter a new steady state appropriate for the diminished protein intake from food. Under the experimental conditions of a protein-free diet, protein synthesis and breakdown continue by reutilizing amino acids. This process becomes very efficient, but some amino acids are still catabolized and nitrogen is lost in the urine and, to a lesser extent, in the feces. This process, termed the obligatory nitrogen loss, has been studied in young adults fed protein-free diets (13, 14) and was reviewed by the most recent international working group (11). Values are remarkably constant. In a series of 11 studies involving > 200 adults aged 20–77 y tabulated by FAO/WHO/UNU (11), obligatory nitrogen losses averaged 53 mg·kg⁻¹·d⁻¹ (range 41–69 mg·kg⁻¹·d⁻¹).

The amounts of nitrogen lost in sweat, hair, nails, sloughed skin, and various body secretions and excretions are small but not negligible. Under conditions of light activity at a comfortable temperature, nitrogen losses in sweat from acclimated persons are as low as 150 mg/d but they may range up to 500 mg/d for subjects with a high protein intake and can increase considerably above this for people doing heavy work and sweating profusely (15–18). A nitrogen loss of 250 mg/d (3–4 mg/kg body wt) through all these sources is reasonable for adult men doing light work and exposed only intermittently to high temperatures. Minor routes of nitrogen loss include saliva, sputum, menstruation, and seminal ejaculation (11, 15), which average ~2 mg/kg body weight. Overall miscellaneous losses are now estimated to be 8 mg·kg⁻¹·d⁻¹ (11).

The processes of protein synthesis and breakdown are energy dependent and thus are sensitive to dietary energy deprivation. Consequently, the body’s energy balance becomes an important factor in determining nitrogen balance and influences the apparent utilization of dietary protein. Both basal energy needs and the total amount of protein turnover in a day are related to active tissue mass. It has not, however, proved possible to establish a constant numerical relationship, covering all age ranges, between basal energy needs and either protein requirement or obligatory nitrogen loss (11). Nevertheless, it has long been known that utilization of dietary protein is influenced by energy intake (19–23).

### Requirements for total nitrogen

In several previous reports of the recommended dietary allowances (RDA) committee (eg, 24) and in two international reports (10, 25), a factorial method was used for predicting the protein requirements of adults and some other age groups. This method involved measuring obligatory nitrogen losses (eg, in urine, feces, and skin) from persons with dietary intakes devoid of protein but otherwise adequate. The requirement for dietary protein was considered to be the amount needed to replace this loss after adjustment for inefficiency in utilization of dietary protein and for the quality of the dietary protein consumed (eg, in amino acid pattern and digestibility). For children and for pregnant and lactating women, an additional amount of protein for tissue growth or milk formation was incorporated into this factorial estimate of requirements.

The FAO/WHO report (10) in 1973 was the first to consider whether the obligatory nitrogen loss gave a valid prediction of the amount of dietary protein needed to meet minimum physiological requirements. After an evaluation of balance studies in which egg and milk proteins were fed to infants, children, and adults at amounts lower than or close to requirements, it was concluded that high-quality proteins were not utilized with the 100% efficiency that had been assumed (10). It was proposed that the average requirement for egg and milk protein should be 30% greater than the factorial estimate at all ages. Reexamination of the data suggested that the addition should have been in the order of 45% (26). Because of the assumptions required and the possible variations of the correction factors with age, the validity of the factorial approach has been questioned and the use of modified nitrogen-balance procedures for the assessment of adult protein needs was advocated by the most recent international working group (11).

### Nitrogen balance

Nitrogen balance involves the determination of the difference per day between the nitrogen intake and the amount excreted in urine, feces, and sweat together with minor losses occurring by other routes. Nitrogen-balance response curves involve feeding a series of different amounts of dietary protein and determining nitrogen balance at each of these amounts. The requirement is estimated by extrapolating or interpolating the nitrogen balance data to the zero balance point (nitrogen equilibrium) for adults or to a defined level of positive balance (to allow for growth) for children. Technical problems associated with nitrogen balance are associated with difficulties in exact measurement of intake and output of nitrogen (13, 27, 28). By use of a response curve, these errors may be minimized.

Studies in experimental animal and human subjects demonstrated that nitrogen balance is not linear throughout the entire submaintenance range and that the slope of the line linking nitrogen balance to nitrogen intake decreases considerably as
intakes producing zero balance are approached and slightly exceeded (29, 30). Other variations in experimental design contributing to the differences include amount of dietary energy intake and physical activity (22, 31, 32). Increased requirements can also be affected by nitrogen losses through routes other than urine and feces, the most important of which is the skin. Appreciable amounts of nitrogen (mainly as urea) can be lost in sweat; in conventional balance studies these losses are not determined and an estimated allowance is made for them. This allowance has now been increased (11) to 8 mg N·kg body wt⁻¹·d⁻¹.

Another important consideration is the length of time needed to achieve a steady state at given protein intakes. Because adjustments in the urinary excretion of nitrogen do not occur immediately after a change in nitrogen intake, it is necessary to allow a sufficient period for the adjustment of nitrogen output to the new nitrogen intake (30).

Because of these limitations of short-term balance studies, longer studies should be undertaken to provide a better basis for protein requirements. These would permit the measurement of variables such as alterations in lean body mass or in growth rate in children, who respond more slowly to dietary inadequacy. In the few long-term studies reported, investigators explored the usefulness of various biochemical indices, for example, serum aspartate and alanine amino transferase activities (33), but agreement on a sensitive and reliable marker has not been reached (11, 12, 34).

Long-term balance studies have been conducted only at a single protein intake, but the goal of both short-term and long-term nitrogen balance studies is to find the minimum protein intake that will maintain the overall status quo in relation to the mass of body protein. Large losses of body protein can be endured without loss of life but the extent of loss that still permits optimal function is unknown. In consequence of these considerations, the use of nitrogen-balance response curves in short-term studies and nitrogen balance in long-term studies have become the preferred methods for assessing adult protein needs rather than the factorial approach used previously.

**Amino acid requirements**

The required amounts of the nine essential amino acids must be provided in the diet but because cystine and tyrosine can replace part of the requirement for methionine and phenylalanine, respectively, these amino acids are also considered when diets are evaluated. Studies on the essential amino acid requirements of infants (2, 35), young children (36), older children (37), men (38), and women (39) have been published and reviewed (10, 11, 40). All these amino acid requirements were determined in the presence of adequate levels of total nitrogen or nonessential amino acids. Estimates for amino acid requirements for various age groups are shown in Table 1 and indicate that the adult requirements are very low. However in studies of whole-body lysine, leucine, valine, and threonine oxidation rates using stable-isotope techniques, Young et al (41–45) suggested that adult requirements, at least for these four essential amino acids, may be considerably greater than present estimates derived from nitrogen balance techniques. Amino acid requirements (10, 11, 40) for adults may thus need reevaluation (46).

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
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<tbody>
<tr>
<td>Estimates of daily amino acid requirements at different ages</td>
</tr>
<tr>
<td>Amino acid</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Histidine</td>
</tr>
<tr>
<td>Isoleucine</td>
</tr>
<tr>
<td>Leucine</td>
</tr>
<tr>
<td>Lysine</td>
</tr>
<tr>
<td>Methionine</td>
</tr>
<tr>
<td>Phenylalanine</td>
</tr>
<tr>
<td>Threonine</td>
</tr>
<tr>
<td>Tryptophan</td>
</tr>
<tr>
<td>Valine</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

* From FAO/WHO (10). Not used for subsequent calculation of amino acid scoring pattern.
† Calculated from amino acid composition pattern of human milk (Table 2) using body weight and nitrogen requirement of a child aged 1 y.
‡ From Pineda et al (36).
§ Tabulated by NAS-NRC (40).
‖ From FAO/WHO (10).
¶ From FAO/WHO/UNU (11).
** Without histidine.

It is now agreed that histidine is an essential amino acid for adults (5–7) but requirement values are difficult to establish because low intakes are required for long periods before deficiency symptoms occur. Kopple and Swendsen (7) demonstrated that nitrogen balance values became less positive at intakes < 2 mg·kg⁻¹·d⁻¹, but FAO/WHO/UNU (11) suggested a probable histidine requirement for adults of 8–12 mg·kg⁻¹·d⁻¹. This estimate seems to include a considerable margin of safety.

From Table 2, which is partially derived from Table 1, it can be seen that the proportion of daily nitrogen needs required in the form of essential amino acids estimated by FAO/WHO/UNU (11) is far less for the adult than for the young child. This implies that an evaluation of dietary protein quality based on the pattern of amino acid requirements for infants or young children will lead to an underestimation of the effectiveness of that protein in meeting requirements of older children and adults. The average dietary pattern of intake of amino acids in the United States is also shown in Table 2 and indicates that, except for infants, most natural diets should provide sufficient amounts of amino acids if total protein and food energy needs are met. This would remain true (46) even if the considerably higher estimates of amino acid requirements for adults by Young et al (41–45) are confirmed.

Present data still contain discrepancies and demonstrate the unsatisfactory state of knowledge concerning amino acid requirements. Nevertheless, these values are the best presently available and serve as the basis for the amino acid scoring of diets.
TABLE 2
Pattern of amino acid requirement at various ages compared with amino acid intake patterns and the composition of cow milk, beef, and wheat

<table>
<thead>
<tr>
<th>Amino acid</th>
<th>Infants, 1 y</th>
<th>Preschool, 2–5 y</th>
<th>Child, 10–12 y</th>
<th>Adult</th>
<th>Amino acid content of different foods‡</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R S</td>
<td>R S</td>
<td>R S</td>
<td>R S</td>
<td>Cow milk Beef Wheat</td>
</tr>
<tr>
<td>Histidine</td>
<td>165 170</td>
<td>125 169</td>
<td>115 169</td>
<td>100</td>
<td>169 213 120</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>290 336</td>
<td>190 338</td>
<td>180 332</td>
<td>80</td>
<td>294 301 232</td>
</tr>
<tr>
<td>Leucine</td>
<td>580 540</td>
<td>440 504</td>
<td>290 501</td>
<td>120</td>
<td>594 507 379</td>
</tr>
<tr>
<td>Lysine</td>
<td>415 432</td>
<td>390 434</td>
<td>290 434</td>
<td>100</td>
<td>488 556 159</td>
</tr>
<tr>
<td>Methionine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plus cystine</td>
<td>265 195</td>
<td>165 217</td>
<td>145 216</td>
<td>105</td>
<td>206 249 225</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>plus tyrosine</td>
<td>450 525</td>
<td>415 503</td>
<td>145 502</td>
<td>120</td>
<td>638 500 462</td>
</tr>
<tr>
<td>Threonine</td>
<td>270 252</td>
<td>225 248</td>
<td>180 249</td>
<td>55</td>
<td>275 287 192</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>105 75</td>
<td>75 74</td>
<td>55 74</td>
<td>30</td>
<td>88 70 68</td>
</tr>
<tr>
<td>Valine</td>
<td>345 369</td>
<td>230 350</td>
<td>165 351</td>
<td>80</td>
<td>400 313 270</td>
</tr>
<tr>
<td>Total</td>
<td>2875 2894</td>
<td>2245 2837</td>
<td>1525 2828</td>
<td>795</td>
<td>3150 2995 2105</td>
</tr>
<tr>
<td>With histidine</td>
<td>2715 2724</td>
<td>2120 2668</td>
<td>1415 2659</td>
<td>695</td>
<td>2981 2780 1990</td>
</tr>
<tr>
<td>Without histidine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* From FAO/WHO/UNU (11). Calculated from mg/g protein values by using protein = N × 6.25 and rounded to nearest 5 mg.
† Calculated from USDA (47) data courtesy Massachusetts Nutrient Data Bank.
‡ From FAO (48).

Factors affecting the protein value of diets

The knowledge that proteins differ in their ability to support growth goes back to some of the earliest studies in nutrition. Many techniques for evaluating protein quality were devised and were reviewed (10, 11, 49–54). Protein-quality measurements of individual foods are useful for comparing the nutritive value of different lots of a single source, such as an infant formula or a processed food, but they do not give useful information on complex human diets. For this purpose amino acid scoring has proved suitable.

Scoring does have limitations (51, 54). These include 1) amino acid composition does not reveal protein digestibility or amino acid availability; 2) protein utilization is affected not only by the amount of the limiting amino acid but also by the amounts of essential amino acids present in high amounts and by the amount of nonspecific nitrogen; 3) although not strictly a protein quality consideration, the presence of toxic materials such as trypsin inhibitors, hemagglutinins, and polyphenol compounds is not revealed by amino acid analysis but can affect biological response; 4) because of amino acid recycling, especially when limited by lysine, there may be big discrepancies between score and biological response for low-quality proteins; 5) there are disagreements about the selection of reference patterns, which may vary with age; and 6) amino acid composition data are not always accurate and adequately reproducible (55).

Amino acid scoring was discussed in several reviews and texts (50–54) as well as in a series of international reports (10, 11, 49). Two major factors make application of scoring more difficult than the apparently simple and logical rationale behind it: requirements for amino acids vary with age and physiological state and the amino acid composition of a protein after hydrolysis does not necessarily indicate that the amino acids are all equally available for protein synthesis.

Because proteins are known to differ in their ability to support growth, requirement values have been expressed in terms of reference protein (49) or by a less rigorous but more realistic definition as proteins providing adequate amounts of essential amino acids and having a high degree of digestibility such as are found in the proteins of hen egg, cow milk, meat, and fish (11). To apply the recommended allowances of high-quality protein to diets containing other possibly poorer protein sources, it is necessary to consider the essential amino acid patterns provided by the mixed dietary proteins and their relative digestibilities. Upward adjustments in the recommended allowances may then be made to allow for the mixture of dietary proteins habitually consumed.

Digestibility

Protein digestibility is determined as a percentage by measuring nitrogen in the food and feces of subjects on a diet containing test protein:

\[
\frac{(I - F) \times 100}{I}
\]

where I is intake of nitrogen and F is fecal nitrogen excretion on a test diet. This is called apparent digestibility.

Endogenous fecal losses from subjects consuming a nonprotein diet may also be considered in these calculations:
TABLE 3  
Values for the digestibility of protein in humans*

<table>
<thead>
<tr>
<th>Protein source</th>
<th>True digestibility %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>97 ± 3</td>
</tr>
<tr>
<td>Milk, cheese</td>
<td>95 ± 3</td>
</tr>
<tr>
<td>Meat, fish</td>
<td>94 ± 3</td>
</tr>
<tr>
<td>Maize</td>
<td>85 ± 6</td>
</tr>
<tr>
<td>Rice, polished</td>
<td>88 ± 4</td>
</tr>
<tr>
<td>Wheat, whole</td>
<td>86 ± 5</td>
</tr>
<tr>
<td>Wheat, refined</td>
<td>96 ± 4</td>
</tr>
<tr>
<td>Oatmeal</td>
<td>86 ± 7</td>
</tr>
<tr>
<td>Peanut butter</td>
<td>95†</td>
</tr>
<tr>
<td>Soyflour</td>
<td>86 ± 7</td>
</tr>
<tr>
<td>Beans</td>
<td>78†</td>
</tr>
<tr>
<td>Mixed US diet</td>
<td>96‡</td>
</tr>
</tbody>
</table>

* ± SD. Adapted from FAO/WHO/UNU (11).  
† Standard deviation not available.  
‡ Recalculated from apparent digestibility by using \( F_a = 12 \text{ mg N/kg} \).

\[
I = \frac{1 - (F - F_a) \times 100}{1}
\]

where \( F_a \) is fecal nitrogen excretion on a nonprotein diet. This is called true digestibility. \( F_x \) need not always be determined directly, especially if the diet contains only a small amount of fiber; 12 mg N·kg body wt\(^{-1}\)·d\(^{-1}\) was proposed (11) as an applicable value when normal amounts of fiber are consumed. This value is reasonable and can be used to convert apparent digestibility values into true digestibility.

Differences in digestibility result from intrinsic differences in the nature of food protein (nature of the cell wall), from the presence of other dietary factors that modify digestion (eg, dietary fiber, polyphenols such as tannins, and enzyme inhibitors), and from chemical reactions (eg, binding of the amino groups of lysine and cross-linkages), which may affect the release of amino acids by enzymatic processes. Because differences in digestibility affect the utilization of protein, an adjustment for digestibility is necessary in translating requirements for reference protein to recommended intakes of ordinary mixtures of dietary proteins. Representative data on the digestibility of some selected proteins are shown in Table 3.

Amino acid scoring patterns

Although earlier scoring systems were based on egg (50) or a hypothetical reference protein (49), FAO/WHO introduced a procedure in 1973 (10) whereby the amino acid requirements (mg·kg\(^{-1}\)·d\(^{-1}\)) of the various age groups were divided by the daily protein or nitrogen requirements (g·kg\(^{-1}\)·d\(^{-1}\)) for the same age groups so as to give patterns of requirements for each age group (mg amino acids/protein or nitrogen).

Because protein quality is most critical for the young, scoring patterns appropriate to children were originally applied to all age groups. The resulting numerical values (scores) derived from amino acid analysis of various protein sources were approximately the values obtained from animal assays such as net protein utilization (NPU) and net protein ratio (NPR) (51), assays conducted on young growing animals. This agreement appeared to validate the scoring system and a single scoring system based on the infant-child requirement was adopted (10) for all ages despite recognition of the wide differences in amino acid requirements between children and adults. In practice this gave an extra margin of safety to adult needs.

The only new data available to the most recent international group studying amino acid requirements (11) were those from a study of 2- to 7-year-old children in Guatemala (36). To derive patterns at various ages, the 1985 group (11) used the same procedure that was used in 1973 (10) except that the amino acid pattern of human milk was used for the requirements of infants aged < 1 y. The values obtained are shown in Table 2 together with the amino acid compositions of beef, milk, wheat, and the average US diet as estimated from food consumption data (47). A significant departure from previous practice advocated by FAO/WHO/UNU (11) was that several age-dependent scoring patterns were proposed. It is now explicitly recommended by the international group that protein quality is not an unchanging attribute of a protein but can vary with the age of the consumer of that protein.

Only four essential amino acids are likely to affect the protein quality of mixed human diets: lysine, the sulfur-containing amino acids (methionine plus cystine), threonine, and tryptophan. Nevertheless, values for all the essential amino acids are tabulated in Table 2. To adjust for amino acid composition, a score is calculated according to the most limiting amino acid, ie, the one in greatest deficit, for the age group involved. Previously, scores were calculated without accounting for digestibility (10). As a result use of the score alone may lead to an overestimation of the capacity of some proteins to meet physiological requirements. Therefore, the score obtained should be multiplied by digestibility and thus becomes analogous to the biologically determined net protein utilization.

Amino acid score

\[
= \frac{\text{content of individual essential amino acid (mg/g N)}}{\text{content of same amino acid in reference pattern (mg/g N)}}
\]

The lowest value obtained is the score (mg/g protein values can also be used) and should be expressed as a fraction of unity. Then

Estimated net protein utilization

\[
= \text{amino acid score} \times \text{digestibility}
\]

where amino acid score and digestibility are expressed as fractions. The amino acid score should be based on the appropriate pattern for age (Table 2) and thus may vary with age. Digestibility can either be from direct dietary determinations or the values can be taken from Table 3.

For children aged < 1 y, the infant scoring pattern based on the amino acid composition of human milk was used. Human milk is richer in sulfur-containing amino acids than is cow milk, but infants consuming cow milk at the same amount as human milk have satisfactory growth (36). Consequently, for dietary proteins with low amounts of sulfur-containing amino acids, a scoring pattern based on human milk may lead to a slight underestimation of the capacity of dietary proteins to...
meet the physiological requirements of the infant. Nevertheless, breast-fed infants can have satisfactory growth at protein and amino acid intakes below those previously recommended as safe (57), probably because the bioavailability of protein in human milk is high. The pattern for preschool children should be used for children aged 1–5.9 y and the school-child pattern for those aged 6–11.9 y. For children aged > 12 y the adult figure is applicable. The amino acid requirement patterns for pregnant and lactating women have not been determined, but it is generally accepted that the quality of the extra ingested protein should be high. Until better information is available, the infant scoring pattern based on human milk is recommended for use in estimating the additional needs of pregnant and lactating women. This will decrease the score and thus increase the allowances and provide an extra margin of safety.

Protein-energy ratios

Food consumption data for the United States (47) indicate that ~16% of the total food energy is derived from protein. This is termed the protein-energy ratio (P:E) and when expressed as a percentage is

\[
PE \text{ ratio } \% = \frac{\text{protein (g/100 g)}}{[4 \times 100]/\text{food energy (kcal/100 g)]}
\]

Despite wide variations in food energy intake, this ratio remains similar for both sexes in all age groups. There is also little change as a function of household income, urbanization, or race.

The ratio of protein to energy in a diet is a useful indicator of protein sufficiency (58, 59). Problems can arise however in establishing appropriate standards for that ratio (11), because energy needs change greatly with an individual's overall activity level whereas protein requirements are much more constant. Thus dietary protein-energy ratios are situation specific, and it is frequently inappropriate to base reference ratios merely on average protein and energy requirements for groups even when adjusted for weight. Nonetheless, the ratio in the US diet at ~16% clearly is well above the reference ratios of 7–11%, depending on the age group for which ratios are calculated. At first sight it is surprising that the protein-energy ratios, as estimated from mean group requirements, increase with age in apparent contradiction to the widely held and correct view that the protein value of the diet is of greater importance for younger age groups. This occurs because the decrease in average energy needs per unit body weight with age is far steeper than the decrease in protein requirements.

Criteria for assessing protein allowances for the various age groups

In the establishment of a requirement for protein, three major steps were followed:

1) The average needs for highly digestible, high-quality protein, such as egg, meat, milk, or fish, for various age groups were first estimated together with the special additional needs of pregnant and lactating women. The procedures that were followed differed depending on the group being studied.

2) These average values were increased to allow for individual variation so that the allowances (again for highly digestible, high-quality proteins) could become applicable to practically all healthy persons.

3) These estimates were increased even further, because proteins in ordinary mixed diets may, on average, be less digestible and may have poorer amino acid composition (in relation to requirements) than the high-quality proteins used to establish average needs. The amino acid requirement patterns used for comparison varied with age and physiological status. In practice, only a small increase, because of digestibility, was required for adults.

Adults

To determine the protein requirements of young male adults, the recent international group (11) reviewed evidence from both short- and long-term nitrogen-balance experiments. On the basis of short-term data (15, 19, 22, 60–63), protein requirements were recalculated using 8 mg N·kg⁻¹·d⁻¹ for miscellaneous losses. In these studies protein was fed at several levels of intake below and above the amount expected to promote nitrogen equilibrium. From these results, an estimated mean requirement of 0.61 g·kg⁻¹·d⁻¹ of highly digestible, high-quality protein was proposed by the international group (11). This is slightly higher than the value of 0.57 g·kg⁻¹·d⁻¹ recommended as a safe intake by the previous international group in 1973 (10). This earlier recommendation was intended to be 2 SD above the mean requirement. Several long-term studies of 48–89 d in length (21, 31, 33, 64) yielded similar estimates for subjects consuming high-quality protein diets. From the average of the two sets of balance data (i.e., from the long- and short-term studies), a value was obtained that, when rounded, was 0.6 g·protein·kg⁻¹·d⁻¹. This then was taken as the average daily requirement for high-quality proteins, such as those from meat, milk, egg, and fish.

To translate this into an amount sufficient to cover individual variations within a population, a coefficient of variation in requirements is required. No such data were available for long-term studies, but for short-term studies a CV was estimated to be 12.5% (11). A value of 25% (2 SD) above the average requirement would thus be expected to meet the needs of 97.5% of the population if a Gaussian distribution of individual requirements was assumed. Thus 0.75 g·kg⁻¹·d⁻¹ (0.6 × 1.25) became the recommended allowance for high-quality protein. There are less extensive data for young adult women but there was no evidence (65) that requirement values, when adjusted for body weight, were substantially different from those of young adult men. Accordingly, the recommended allowance for good quality, highly digestible protein was set at 0.75 g·kg⁻¹·d⁻¹ for both sexes.

For recommended allowances applicable to those consuming a typical US mixed diet, these values must be adjusted for amino acid composition and digestibility. In Table 2 the amino acid score is calculated by comparing the pattern of requirement for the adult with the pattern in the US food supply as calculated from food consumption data (47). Because the food supply pattern was well above the pattern for adult requirements, the amino acid score for all adults was taken as 1.00. For digestibility, a value of 0.90 was assumed for the US diet. This is slightly below the average determined value (Table 3) but it does make some allowance for the consumption of high-
TABLE 4
Derivation of protein allowance during pregnancy

<table>
<thead>
<tr>
<th>Trimester</th>
<th>Average additional storage*</th>
<th>Corrected for +30%† conversion efficiency‡</th>
<th>Additional high-quality protein§</th>
<th>Quality correction factor¶</th>
<th>Additional protein allowance g/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.11</td>
<td>0.14</td>
<td>0.20</td>
<td>1.3</td>
<td>0.63</td>
</tr>
<tr>
<td>2</td>
<td>0.52</td>
<td>0.68</td>
<td>0.97</td>
<td>6.1</td>
<td>0.63</td>
</tr>
<tr>
<td>3</td>
<td>0.92</td>
<td>1.20</td>
<td>1.71</td>
<td>10.7</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Average over entire pregnancy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.0</td>
</tr>
</tbody>
</table>

* From FAO/WHO/UNU (11). Assumes 3.3-kg infant birth weight.  † CV of birth weight assumed to be 15%.  ‡ 70% conversion efficiency of dietary protein to tissue protein assumed. § N × 6.25. ¶ Includes amino acid composition and digestibility.

er-fiber diets and gives a small extra margin of safety. As a result of extensive discussions by the 1980–1985 RDA Committee, population median weights (66) were used as reference body weights for all age groupings of the US population rather than desirable body weights, which had been used previously for adults (24). The age groupings were also revised and were considered to reflect more accurately physiological realities. The score multiplied by digestibility (estimated NPU) for the adult diets is thus 0.90 (1.00 × 0.90) and the daily allowance for a 79-kg male aged 25–49.9 y becomes 66 g [(0.75 × 79)/0.90]. By a similar calculation, the allowance for a 62-kg female becomes 52 g/d [(0.75 × 62)/0.90].

Pregnancy

Additional protein is required during pregnancy almost equally for the mother and the fetus (67). Augmented maternal protein synthesis is needed for expansion of the blood volume, uterus, and breasts, and fetal and placental proteins are synthesized from amino acids supplied by the mother. The magnitude of the required increase remains uncertain because different methods of estimation yield different results.

The theoretical or factorial approach toward estimating requirements during pregnancy is based on the known quantities of protein accumulation during gestation derived from analyses of fetuses and placentas and indirect estimates of maternal body composition. The estimated total protein accumulation of a woman who gains 12.5 kg during pregnancy and delivers a 3.3-kg infant is 925 g, or 3.3 g/d throughout pregnancy (68). The rate of storage, however, is not constant. For the first, second, and third trimesters, respectively, estimates for storage are 0.11, 0.52, and 0.92 g/d of extra nitrogen (Table 4). Evidence from animal studies (69, 70) suggest that protein may be stored in early gestation and then mobilized at later stages of pregnancy. Consequently, increased protein needs during pregnancy may be more uniform than these figures for protein deposition indicate.

A more direct experimental procedure for estimating protein requirements during pregnancy is based on nitrogen balance. A number of such studies in various laboratories indicated quite consistently that nitrogen is retained during pregnancy at rates greater than those predicted from fetal placental growth and known maternal tissue hypertrophy (68, 71, 72). During the entire pregnancy, observed nitrogen gains, after correction for sweat and other miscellaneous losses, are about twice the theoretical (1.1 vs 0.5 g/d) (73). This discrepancy may be partly due to the difficulties and inaccuracies associated with the conduct of balance studies (74). However, data on changes in body weight and body potassium also indicate that nitrogen retention is greater than can be accounted for only by the fetus and maternal supportive tissue (75, 76). This suggests that protein may be retained by the pregnant woman at sites other than those associated with reproduction, for example, in skeletal muscle; this possibility is supported in part by the analyses of animal carcasses (73).

Conclusions such as these are discounted in a study in which 12-d nitrogen balance studies were performed on 68 primigravidas in Aberdeen, Scotland, who were between their 30th and 34th weeks of pregnancy (77). For average daily protein and food energy intakes of 76 g and 2470 kcal, respectively, a mean apparent retention was +1.22 g N/d (range, −0.69 to +3.16 g/d). Mean skin and miscellaneous nitrogen losses for adults are now considered to be 8 mg/kg (11) and would approximate to 0.5 g/d. True nitrogen retention would thus average +0.72 g/d (1.22–0.50 g/d) during the third trimester—a value not greatly different from the factorial estimates shown in Table 4. The conclusion by these investigators was that there was no evidence of nitrogen storage greater than that required for the known sites, at least in the third trimester (77). Although there are still some discrepancies between factorial and nitrogen balance estimates of nitrogen gain during pregnancy, it is recommended that assessment of needs should be based on an increment of 925 g protein—the average gain plus 30% (2 SD of birth weight). This should cover the protein gains of virtually all normal women during pregnancy. These values for protein gain must be adjusted for the efficiency (generally assumed to be 70%) with which dietary protein is converted to fetal, placental, and maternal tissues (Table 4).

Dietary surveys in developed countries indicate that preg-
nant women on self-selected diets generally consume somewhat larger amounts of protein than their requirements calculated theoretically. Moreover, satisfactory intakes of protein tend to be associated with improved reproductive outcome (78–81). Such epidemiological data are however confounded by the metabolic interrelationships between protein and energy. Within limits nitrogen balance can be improved by increasing intake of either protein or energy alone (79, 82, 83). According to the calculations of Calloway (71), which were derived from previously reported balance studies, equivalent effects on nitrogen balance will result from the addition of 100 kcal/d or of 0.28 g N/d (1.75 g protein/d). In practice, however, low protein intakes tend to be associated with low energy intakes. Therefore, utilization of dietary protein may not be the limiting factor. Evidence from studies in Guatemala (83) suggest that an increased intake of energy alone benefits the development of the unborn child and increases its birth weight.

The derivation of the estimates for additional protein during pregnancy is shown in Table 4. The calculated additional daily needs of highly digestible, high-quality protein are 1.3, 6.1, and 10.7 g during the first, second, and third trimesters of pregnancy, respectively. These values must be increased to allow for digestibility and amino acid composition of ordinary diets. Until more information is available, it is prudent to base calculations for the quality of the additional protein on the requirement pattern for infants. The amino acid score for the US dietary supply of the adult using the infant requirement pattern (Table 2) is 0.70, with tryptophan being the apparent limiting amino acid. When adjusted for a digestibility factor of 0.90, the estimated NPU becomes 0.63. Thus, the additional daily recommended allowances are 2, 10, and 17 g protein, respectively, for the three trimesters. The extra 2 g for the first trimester is sufficiently small that it will be exceeded by the habitual diets of most nonpregnant females. Therefore, for late diagnosis of pregnancy there is little nutritional risk at least for protein recommendations.

These recommendations are considerably below the 30 g/d of additional protein recommended in the 9th edition RDAs (24). This recommendation appears to have been in error, because the retention of 16 mg N·kg body wt⁻¹·d⁻¹ together with a 50% utilization of dietary protein, which were given as the basis of the recommendation, would only translate to 20 g/d for a 58-kg female with a 12-kg weight gain even assuming an average protein quality of 70%. The current requirement recommendations are considered generous because a considerable margin of safety has been introduced by the use of the highest possible standard (infant pattern) for the protein quality of the additional protein required in pregnancy and are above those recommended by FAO/WHO/UNU (11).

**Lactation**

The average protein (N × 6.25) content of mature human milk is 10.6 ± 1.2 g/L (84). A similar estimate (11 g/L) was reported by FAO/WHO/UNU (11) except for the first month where it was 13 g/L. Recent determinations of human-milk composition in the United States based on a study of 40 mothers in the first 4 mo of lactation (57) demonstrate a fall in protein content from 13.6 to 11.2 g/L during this period. It is well known that between 20% and 25% of the nitrogen in human milk is nonprotein nitrogen (ie, not precipitated by trichloroacetic acid). However, much of the nonprotein nitrogen in human milk may be fully utilized for protein synthesis.

The protein requirement for lactation can be estimated by multiplying 750 mL, the mean volume of milk produced (PM Farrell, personal communication, 1985), by the protein content and then making allowance for 70% efficiency in the conversion of dietary protein to milk protein. To give a margin of safety, milk protein content was assumed to be 13.0 g/L (ie, the mean plus 2 SD); thus the additional daily maternal requirement for high-quality, highly digestible protein was calculated as follows:

\[
\text{Additional protein required} = \frac{0.750 \times 13.0}{0.70} = 14 \text{g/d}
\]

If the amino acid pattern in human milk is used to calculate protein quality for the additional protein needs of lactation, then, as for pregnancy, estimated NPU becomes 0.63 and an additional 22 g (14/0.63) per day from the average US diet is recommended for the first 6 mo of lactation. The mean volume of milk produced in the second 6 mo in the United States is less well documented. World-wide data (11) indicate a fall of ~20% in mean milk volume for the second 6 mo of lactation. If this is accepted, then the recommended additional allowance in this period becomes 18 g/d.

**Infants, children, and adolescents**

During the first year of life, the protein content of the body increases from 11% to 14.6% and body weight increases by ~7 kg. The average increase in body protein is ~3.5 g/d during the first 4 mo of life and 3.1 g/d during the next 8 mo (56). By age 4 y, body protein content reaches the adult value of 18–19% body weight (85). As the growth rate drops rapidly after the first year of life, the maintenance requirement represents a gradually increasing proportion of the total protein requirement.

For the first months of life, requirements are based on intake data because of the difficulties in estimating accurate allowances for growth and maturation. Infants breast-fed by healthy, well-nourished mothers or fed by bottle (11, 56, 57, 86) can grow at a satisfactory rate for 4–6 mo. Measurements of human-milk composition (11) demonstrated that protein intakes ranged from 2.43 g·kg⁻¹·d⁻¹ in the first month to 1.51 g·kg⁻¹·d⁻¹ in the fourth month. Although boys consumed slightly more milk than did girls during this period, requirements were almost identical when expressed on a body weight basis. For the first 3 mo these averaged 2.04 g·kg⁻¹·d⁻¹, falling to 1.73 g·kg⁻¹·d⁻¹ for the next 3 mo. In a recent study of breast-fed infants in the United States (57), satisfactory growth was however observed at a mean protein intake of only 1.68 g·kg⁻¹·d⁻¹ (N × 6.25) during the first 3 mo. Nevertheless a rounded value of 2.00 g·kg⁻¹·d⁻¹ was selected as an allowance, but for this age group it is recommended that protein requirements should be considered in relation to energy needs. The protein needs of an infant up to age 4 mo will be met if the energy needs are met, provided the food contains protein of quality and quantity equivalent to that of breast milk. This implies that some 8% of the food energy in the form of high-quality protein is desirable.

A modified factorial procedure was also used by the international working group (11) to calculate the protein needs of infants. The values obtained for the first 2 mo of age were slightly
lower than those based on intake, but the estimates from the two procedures became almost identical in the third and fourth month. The modified factorial approach was subsequently used to estimate needs for all older children. Maintenance values were interpolated from a number of published nitrogen balance studies on infants and young adults (62) and were considered to decline progressively from 120 mg N·kg⁻¹·d⁻¹ in the infant to the young-adult value of 98 mg·kg⁻¹·d⁻¹. The period from age 6 to 12 mo is clearly very critical because of rapid growth and because the child increasingly relies on supplementary foods. Table 5 illustrates the detailed steps involved in the calculations of daily allowances by the modified factorial approach. The mean rate of nitrogen accretion during growth can be estimated from the expected weight gain at the 50th percentile (87) and the nitrogen concentration in the body.

The FAO/WHO/UNU group (11) also recognized the need for continuous provision of protein in anticipation of extra, unpredictable demands from the daily variations in growth rate, because protein provided on a day of no growth is probably not held in reserve for later growth. There were no data on which to base reliable estimates for the extra protein needed for this purpose, but a value 50% higher than the estimated daily nitrogen increment was considered realistic (11).

Dietary protein was assumed to be used with the same efficiency for growth as for maintenance and it was concluded that a correction factor of 70% was appropriate for all ages. Finally, a correction must be made for the variability of growth between individuals. This was assumed to have a CV of 12.5%—the same as that established for adults (11). An example of this modified factorial approach is shown in Table 5.

Tabulated values for daily protein allowances for the various age and sex groupings are shown in Table 6. All values are initially expressed as high-quality, highly digestible proteins such as meat, milk, fish, and eggs. To convert these values to daily allowances of average US dietary protein, they must be corrected for amino acid composition and digestibility. A mean nitrogen digestibility of 0.90 was used throughout and an amino acid score was calculated using the appropriate pattern for the various ages as shown in Table 2. If formulas based on cow milk are consumed, digestibility may be <100%. For calculating daily allowances of US dietary protein, the dietary protein is assumed to originate from 100% milk formula for children up to age 3 mo, 75% from milk and 25% from solid foods for age 3–6 mo, and 50% from each source for age > 6 mo. For ages 1.0–1.9 y and 6.0–7.9 y, a scoring pattern is interpolated midway between adjacent requirement patterns to smooth transitions.

Final recommended allowances for US dietary protein thus range from somewhat > 2 g·kg⁻¹·d⁻¹ in the first year of life to ~1 g·kg⁻¹·d⁻¹ for adolescents.

Elderly people

The lean body mass content of the adult body diminishes with age. More specifically, muscle diminishes extensively and is compensated for by an increase in body fat while nonmuscle mass is not affected (88). These changes in muscle mass are

---

**TABLE 5**
Examples of the derivation of protein allowances for children and adolescents by a factorial procedure adapted from FAO/WHO/UNU (11)*

<table>
<thead>
<tr>
<th>Age</th>
<th>Nitrogen increment †</th>
<th>Nitrogen increment × 1.5‡</th>
<th>Nitrogen increment × 1.5 plus correction for efficiency at 70%§</th>
<th>Maintenance</th>
<th>Total</th>
<th>Daily allowance reference protein</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg·kg⁻¹·d⁻¹</td>
<td>mg·kg⁻¹·d⁻¹</td>
<td>mg·kg⁻¹·d⁻¹</td>
<td>g/kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both sexes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–2.9 mo</td>
<td>96</td>
<td>144</td>
<td>206</td>
<td>120</td>
<td>326</td>
<td>2.00†</td>
</tr>
<tr>
<td>3–5.9 mo</td>
<td>47</td>
<td>70</td>
<td>100</td>
<td>120</td>
<td>220</td>
<td>1.38</td>
</tr>
<tr>
<td>6–1.9 mo</td>
<td>34</td>
<td>51</td>
<td>73</td>
<td>120</td>
<td>193</td>
<td>1.21</td>
</tr>
<tr>
<td>1 y</td>
<td>16</td>
<td>25</td>
<td>36</td>
<td>119</td>
<td>155</td>
<td>0.97</td>
</tr>
<tr>
<td>5 y</td>
<td>9</td>
<td>13</td>
<td>19</td>
<td>116</td>
<td>135</td>
<td>0.84</td>
</tr>
<tr>
<td>9 y</td>
<td>8</td>
<td>12</td>
<td>17</td>
<td>111</td>
<td>128</td>
<td>0.80</td>
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<td>Males (y)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>12</td>
<td>9</td>
<td>13</td>
<td>19</td>
<td>108</td>
<td>127</td>
<td>0.79</td>
</tr>
<tr>
<td>17</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>103</td>
<td>110</td>
<td>0.69</td>
</tr>
<tr>
<td>Females (y)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>7</td>
<td>10</td>
<td>14</td>
<td>108</td>
<td>122</td>
<td>0.76</td>
</tr>
<tr>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>103</td>
<td>103</td>
<td>0.64</td>
</tr>
</tbody>
</table>

* Note: The calculations shown are examples of the derivation of requirements at various ages and will not always agree with the group mean values shown in Table 6.
† Increment for growth (11).
‡ 50% additional nitrogen increment to allow for daily variation in growth rate and presumed inability to store amino acids for when maximum growth occurs (11).
§ Assuming a 70% efficiency of dietary protein utilization for growth.
∥ Individual variability. The CV for both maintenance and growth was assumed to be 12.5%.
¶ Value selected from intake data and is slightly below that calculated from factorial data.
** Allowance considered to equal mean requirement for infants aged < 3 mo.
TABLE 6
Derivation of the recommended allowances of US dietary protein

<table>
<thead>
<tr>
<th>Age or condition</th>
<th>Weight (kg)</th>
<th>By weight (g/kg)</th>
<th>By time (g/d)</th>
<th>Score†</th>
<th>Estimated NPU ‡</th>
<th>Recommended allowance (g/kg)</th>
<th>By weight (g/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both sexes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-2.9 mo</td>
<td>4.5</td>
<td>2.00</td>
<td>9</td>
<td>1.00</td>
<td>0.90§</td>
<td>2.22</td>
<td>10</td>
</tr>
<tr>
<td>3-5.9 mo</td>
<td>6.6</td>
<td>1.73</td>
<td>11</td>
<td>0.81</td>
<td>0.73</td>
<td>2.37</td>
<td>16</td>
</tr>
<tr>
<td>6-11.9 mo</td>
<td>8.8</td>
<td>1.51</td>
<td>13</td>
<td>0.78</td>
<td>0.79</td>
<td>2.16</td>
<td>18</td>
</tr>
<tr>
<td>1-1.9 y</td>
<td>11</td>
<td>1.21</td>
<td>13</td>
<td>0.82</td>
<td>0.74</td>
<td>1.64</td>
<td>18</td>
</tr>
<tr>
<td>2-3.9 y</td>
<td>14</td>
<td>1.12</td>
<td>16</td>
<td>0.99</td>
<td>0.90</td>
<td>1.24</td>
<td>18</td>
</tr>
<tr>
<td>4-5.9 y</td>
<td>18</td>
<td>1.05</td>
<td>19</td>
<td>0.99</td>
<td>0.90</td>
<td>1.17</td>
<td>21</td>
</tr>
<tr>
<td>6-7.9 y</td>
<td>22</td>
<td>1.02</td>
<td>22</td>
<td>1.00</td>
<td>0.90</td>
<td>1.13</td>
<td>25</td>
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<tr>
<td>8-9.9 y</td>
<td>28</td>
<td>1.00</td>
<td>28</td>
<td>1.00</td>
<td>0.90</td>
<td>1.11</td>
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<tr>
<td>Males (y)</td>
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<tr>
<td>10-11.9</td>
<td>36</td>
<td>0.98</td>
<td>35</td>
<td>1.00</td>
<td>0.90</td>
<td>1.09</td>
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<td>12-17.9</td>
<td>57</td>
<td>0.93</td>
<td>53</td>
<td>1.00</td>
<td>0.90</td>
<td>1.03</td>
<td>59</td>
</tr>
<tr>
<td>18-24.9</td>
<td>73</td>
<td>0.75</td>
<td>55</td>
<td>1.00</td>
<td>0.90</td>
<td>0.83</td>
<td>61 ‡</td>
</tr>
<tr>
<td>25-49.9</td>
<td>79</td>
<td>0.75</td>
<td>59</td>
<td>1.00</td>
<td>0.90</td>
<td>0.83</td>
<td>66 ‡</td>
</tr>
<tr>
<td>50-69.9</td>
<td>77</td>
<td>0.75</td>
<td>58</td>
<td>1.00</td>
<td>0.90</td>
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<td>64 ‡</td>
</tr>
<tr>
<td>&gt;70</td>
<td>74</td>
<td>0.75</td>
<td>56</td>
<td>1.00</td>
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<td>62 ‡</td>
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<tr>
<td>Females (y)</td>
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<tr>
<td>10-14.9</td>
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<td>1.07</td>
<td>47</td>
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<td>15-17.9</td>
<td>56</td>
<td>0.83</td>
<td>47</td>
<td>1.00</td>
<td>0.90</td>
<td>0.92</td>
<td>52</td>
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<tr>
<td>18-24.9</td>
<td>58</td>
<td>0.75</td>
<td>44</td>
<td>1.00</td>
<td>0.90</td>
<td>0.83</td>
<td>48 ‡</td>
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<tr>
<td>25-49.9</td>
<td>62</td>
<td>0.75</td>
<td>47</td>
<td>1.00</td>
<td>0.90</td>
<td>0.83</td>
<td>52 ‡</td>
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<td>50-64.9</td>
<td>65</td>
<td>0.75</td>
<td>49</td>
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<td>0.90</td>
<td>0.83</td>
<td>54 ‡</td>
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<tr>
<td>&gt;70</td>
<td>64</td>
<td>0.75</td>
<td>48</td>
<td>1.00</td>
<td>0.90</td>
<td>0.83</td>
<td>53 ‡</td>
</tr>
</tbody>
</table>

Pregnancy

| 1st trimester   | +1         | 0.70             | 0.63‡         | +2     |
| 2nd trimester   | +6         | 0.70             | 0.63          | +10    |
| 3rd trimester   | +11        | 0.70             | 0.63          | +17    |

Lactation

| 1st 6 mo        | +14        | 0.70             | 0.63‡         | +22    |
| 2nd 6 mo        | +11        | 0.70             | 0.63          | +18    |

* From reference 11.
† Score for the US diet was determined by comparing the intake pattern at various ages with the appropriate requirement pattern (Table 2).
‡ Score X digestibility, where digestibility is assumed to be 0.90.
§ Allows for lower digestibility of cow milk as compared with human milk. Appropriate values should be used for score and digestibility if protein sources other than milk are used. For this age group protein needs will be met if energy needs are met provided that the food contains protein of quality and quantity equivalent to that of human milk.
∥ Daily protein allowances for adults that differ by only a few grams could realistically be averaged; these values however show their derivation.
¶ Based on adult female pattern of intake as compared with the patterns of amino acids in human milk.

related to whole-body protein turnover and changes in the rate of protein synthesis (89). Muscle protein turnover accounts for 30% of the total protein turnover in young adults but only 20% of that in elderly people (90). Serum albumin concentrations and daily albumin synthesis also decrease in elderly people on adequate protein diets (91).

Questions thus arise concerning the extent to which changes in protein metabolism are related to changes in protein requirements. Because 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 through old age (90). Protein needs might be expected to change progressively as the adult becomes older because body composition, physiological functional capacity, physical activity, total food intake, and frequency of disease alter with age. However, there is insufficient information to establish firm recommendations for such a continuum.

The early literature on this subject was reviewed (92); more recent studies continue to be limited in number and their results are equivocal (93). In one study 0.8 g egg protein-kg body wt⁻¹·d⁻¹ was insufficient to maintain nitrogen balance in the majority of elderly men and women studied over a 30-d period (94). In another study, however, this amount of protein appeared to be adequate (95). In both these reports body weight was maintained; however, energy intake was less in the former than in the latter, suggesting that activity patterns may have been different in the two groups (90) or that nitrogen balance was improved by the higher food energy intake. More favorable
energy balances could result in better retention of dietary protein. In another study in which egg protein was fed to the subjects (96), it was concluded that 0.57 g protein/kg body wt was adequate to sustain nitrogen equilibrium at a food energy intake of 30 kcal/kg. This implies that protein (P:E) represented only ~8% of the total energy intake; in contrast, in another study (97) it was found that 0.57 g/kg was insufficient for nearly all subjects and that needs were only barely met at 0.8 g/kg (P:E = 10.7%). These various results are difficult to reconcile but variations in activity level, disease prevalence, and consumption of therapeutic drugs are all potential confounding variables.

Studies on requirements for individual essential amino acids in elderly people have also produced contradictory results (90); some have showed increases and others decreases. Because so few firm data exist, the pattern of requirement for essential amino acids in elderly people is considered to be the same as for younger adults. The conversion of 0.75 g·kg⁻¹·d⁻¹ of high-quality protein to daily allowances for US dietary protein is exactly the same as for younger age groups using an estimated NPU of 0.90. Recommended allowances for protein therefore remain at 0.83 g·kg⁻¹·d⁻¹, or 62 g and 53 g/d for reference males and females, respectively, at age ≥ 70 y. According to Munro (90), it is improbable that high intakes of protein can prevent the aging process in adults, because changes in lean body mass and tissue function occur with habitual protein intakes approximately twice as high as the RDA. Activity levels and, hence, energy intakes are also of major importance in meeting protein needs. Recommended allowances of food energy for a 70-kg, 177-cm male fall from 2800 kcal/d at 21 y to 2000 kcal/d at 75 y (98) whereas the protein allowance remains at 58 g/d. For a 58-kg, 163-cm female over the same age range an allowance of 2300 kcal/d is reduced to 1700 kcal/d, the protein remaining at 48 g/d if the body weight remains unchanged. This implies an increase in the percentage of calories from protein (P:E) from < 9% to > 11% as age increases. To fulfill recommendations (90) that a minimum of 12% of food energy needs should be met by protein for elderly people, slightly higher protein allowances would be needed at the mean food energy intake. The value of 12%, however, would be well exceeded at the low end of the energy requirement range if protein intakes remained the same.

Other effects on protein requirements

There is little evidence that muscular activity increases the need for protein, except for the small amount required for the development of muscles during conditioning (99). However, vigorous activity that leads to profuse sweating, such as in heavy work and sports, increases nitrogen loss from the skin. There is evidence, however, that with acclimatization to a warm environment, the excessive skin loss is reduced (10, 17) and may be partially compensated by decreased renal excretion (10, 11). In view of the margin of safety in the protein allowance, no increment is added for work or training.

Extreme environmental or physiological stress increases nitrogen loss (16, 18). Infections, fevers, and surgical trauma can result in substantial nitrogen loss through the urine and greatly increased energy expenditure (100). Severe infections and surgery should be treated therefore as clinical conditions that require special dietary treatment. During convalescence from an illness that has led to protein depletion, requirements for both protein and energy are elevated because of the need to replace wasted tissues just as they are during periods of rapid growth. Premature infants also require special consideration.

No additional allowance is recommended for the usual stresses encountered in daily living, which can give rise to transient increases in urinary nitrogen output (101), it being assumed that the subjects of experiments forming the basis for the requirement estimates are usually exposed to the same general stresses as the ordinary population.

High protein intakes

As discussed earlier, dietary protein supplies amino acids that are used in the manufacture of body proteins as well as for synthesis of other nitrogen-containing compounds. Amino acids are also a significant source of food energy, contributing on average 12–16% of the daily dietary energy supply. Well-documented pathways described for all the amino acids show that the carbon skeletons enter energy pathways mainly as pyruvate, Krebs cycle intermediaries, or acetyl coenzyme A, and the nitrogen of the amino groups is excreted as urea. It is thus not surprising that the body is normally capable of metabolizing, without apparent hazard, amounts of protein well above recommended dietary allowances. However, certain individuals with various genetic and acquired disorders of amino acid metabolism and nitrogen retention are uniquely unable to tolerate protein intakes in excess of their minimal requirements.

Consumption of high-protein diets may have relevance to the occurrence of osteoporosis and hypercalcemia (102, 103). Some epidemiological studies have suggested a link between high-meat diets and an increased incidence of colon cancer, but the often confounding variables of overnutrition, high-fat and low-fiber diets, and the consequent effects on bile acids and bacterial flora make such conclusions equivocal (104–107).

The hazards of high protein intakes with low fluid volume in the first month of life are well known, but it has been suggested that high-protein diets have a negative effect on kidney disease and increased glomerular sclerosis in normal aging (108). Calcium stone formation in the upper urinary tract (calcium urolithiasis) has been linked with high levels of animal protein consumption (109), but has also been correlated with hypercalcemia and the complex interrelationships among protein, calcium, and phosphorus (103). High animal-protein intake also means high purine intake and consequent high output of uric acid.

The early history of experimental atherosclerosis is replete with studies linking dietary protein to the pathogenesis of the disease (110). After a long period of neglect when fat and cholesterol were assigned the major roles, protein, especially animal protein, is now claimed by some to play a part in the genesis of human hypercholesterolemia and atherosclerosis (111) but denied by others (112). The confounding variables of inter alia fat, fiber, and cholesterol in usual diets, however, make the relationships difficult to evaluate.

Although most diets in the United States contain more than the recommended allowances for protein, there is little reason...
to believe that any harm will result from these intakes. Indeed, longevity data throughout the world are positively correlated with moderate-to-high protein intakes; however, similarly high correlations with generally sanitary and healthful environments preclude simple relationships. The FAO/WHO/UNU group (11) concluded, "There is no reason to suppose that harm will result from an intake that is moderately greater than the individual's physiological need at least within fairly wide limits." There is no evidence at this time to warrant a recommendation to reduce the amount of protein habitually consumed in the United States by normal, healthy individuals.

Protein requirement recommendations compared with 9th edition RDAs

The recommended allowances for protein do not differ greatly from the 9th edition RDAs (24) when considered on a g/kg body wt basis, although the basis for deriving them, especially for the adult, has changed significantly. The reduction of the allowance for very young children from 2.2 to 2.0 g·kg\(^{-1}\)·d\(^{-1}\) is still well above the mean intake of 1.68 g·kg\(^{-1}\)·d\(^{-1}\) (57) found to maintain satisfactory growth in the United States. A more practical recommendation however is that the protein needs for this young age group will be met if the energy needs are met, provided that the food contains protein of quality and quantity equivalent to that of human milk. Allowances for children and adolescents now decrease from 1.64 g/kg at age 1 y to 0.83 g/kg at age 18 y compared with the previous values, which decreased from 1.80 to 0.80 g/kg over the same age range. The slight reductions are a result of a reevaluation of both nitrogen balance data and the factorial calculation procedure used by the FAO/WHO/UNU (11) protein-recommendation panel.

For adults of both sexes, the new value of 0.83 g/kg is very close to the old value of 0.80 g/kg. Nevertheless, the basis for arriving at these values has changed dramatically. The requirements of high-quality protein (fish, meat, milk, or eggs) has been increased by ∼30% from 0.57 to 0.75 g/kg as a result of feeding studies in humans that demonstrated that the previous value was indeed too low (11, 31). However, on the basis of a reevaluation of amino acid digestibility data, the protein value of the US diet is now considered to average 90% rather than the previously accepted value of 70%. These two changes in opposite directions have the effect of leaving the allowance for US dietary protein almost unchanged at 0.83 g·kg body wt\(^{-1}\)·d\(^{-1}\). Recognition that the protein quality of a food is not static but can change with the age of the consumer of that protein is the most significant single change made, because its net effect is to diminish the importance of protein quality for the adult.

The protein requirement in pregnancy is now expressed over the three trimesters at additional intakes of 2, 10, and 17 g/d, respectively. This is considerably below the additional 30 g/d previously recommended for the entire period. This earlier recommendation (24) appears to have been in error, because the retention of 16 mg N·kg body wt\(^{-1}\)·d\(^{-1}\) together with a 50% utilization of dietary protein, which were given as the basis of the recommendation, would only translate to 20 g/d for a 58-kg female with a 12-kg weight gain even assuming an average protein quality of 70%. The current requirement values are considered generous because a considerable margin of safety has been introduced by the use of the highest possible standard (infant pattern) for the protein quality of the additional protein required in pregnancy. For lactation, now separated into the first and second 6 mo, the recommendations of additional 22 g and 18 g, respectively, are almost identical to the previously recommended 20 g/d, despite the reduction in human milk volume to 750 and 600 mL/d for the first and second 6 mo of lactation. These recommendations remain on the basis of factorial calculations of milk composition and quantity together with an estimated 70% conversion efficiency.

Although this article is submitted under a single name and the author was indeed responsible for the initial drafts, this final version is dependent on many other individuals. These include my colleagues, at the University of Massachusetts and elsewhere, who made many suggestions for improvements; the chairman and other members of the 1980-1985 Recommended Dietary Allowances Committee, whose influence in many drafting and revision sessions effected many changes; and finally the anonymous reviewers appointed by the Commission of Life Sciences, National Academy of Sciences, whose erudite comments and criticisms necessitated changes and rebuttals, both of which significantly affected the final form of the manuscript. I am grateful to them all.

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