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Dietary management of moderate malnutrition: Time for a change

André Briend and Zita Weise Prinzo

Introduction

All children with moderate wasting, or with moderate or severe stunting, have in common a higher risk of dying and the need for special nutritional support. In contrast to children suffering from life-threatening severe acute malnutrition, there is no need to feed these children with highly fortified therapeutic foods designed to replace the family diet. Their dietary management should be based on improving the existing diets by nutritional counseling and, if needed, by the provision of adapted food supplements providing nutrients that cannot be easily provided by local foods. Children with growth faltering would also benefit from the same approach.

In contrast to severe acute malnutrition, management of moderate malnutrition (defined by either moderate wasting or stunting) has remained virtually unchanged over the last 30 years. Two broad approaches are used. In most situations, dietary counseling is given to families on the assumption that they have access to all foods needed for feeding their children but lack the knowledge of how best to use them. In the context of food insecurity, or of insufficient access to nutrient-dense foods, food supplements, usually fortified blended flours, are given.

Evaluation of programs for the management of moderate malnutrition so far has yielded mixed results. The review by Ann Ashworth and Elaine Ferguson shows that the dietary advice given is often nonspecific, i.e., not really different from the advice given to well-nourished children, and that the impact of large-scale programs is often uncertain [1]. Doubts about the efficacy of supplementary feeding programs using blended flours have been raised repeatedly over the past 25 years [2, 3]

Many reasons can explain the apparent lack of efficacy of these programs. Diets recommended as part of counseling often have a low nutritional density, insufficient to promote recovery. Often, when nutrient-dense foods are recommended, they are expensive and not really accessible to poor families. When food supplements are given, they are usually made with the cheapest sources of energy (cereals) and proteins (legumes) and often have no added fat. Such supplements often have a nutritional profile (high protein, low fat, and high dietary fiber and antinutrient content) that does not seem the best adapted to promote rapid growth of malnourished children [4].

Clearly, it is time for a change. Children with moderate malnutrition should get the foods that provide all the nutrients they need for full recovery, not just the food choice that represents the cheapest option to provide them energy and proteins. Their efficacy to promote recovery and their accessibility must be the first criteria to consider when making a choice.

Improving the diets of children with moderate malnutrition will not be easy to achieve. First, there are still many uncertainties about what nutrients children with moderate malnutrition, particularly stunted children, need for recovery, as highlighted in the article by Professor Mike Golden [5]. The possible negative effect of antinutrients, which are present in high concentrations in cereals and even higher concentrations in legumes, will complicate the picture, as described in the article by Kim Michaelsen and colleagues [6]. Second, diets with higher nutrient density and lower antinutrient content, which are more appropriate for children with moderate malnutrition, either have a high level of animal-source foods or have to be made from highly processed plant foods, which makes them more expensive than currently recommended diets. Moreover, in the present context of the emerging burden of obesity in many poor countries, promoting diets leading to increased weight is not satisfactory, especially in areas of high

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stunting prevalence [7]. It is important that proposed diets have a limited effect on deposition of fat tissue, promote lean tissue synthesis, and lead to improved functional outcomes, such as improved cognitive development. In this respect, attention should be paid to the essential fatty acid contents of diets, so far a neglected aspect of the management of moderate malnutrition.

There are clear indications from the papers presented at this meeting on how to improve current programs. Dietary counseling should move away from general "fit-for-all" recommendations and should provide specific suggestions that are nutritionally adequate and locally adapted. Program implementers should make sure that the recommended diets are nutritionally adequate and contain all nutrients needed for growth. Adapted computer software can be used to make this assessment more rigorous [8].

Food supplements should be considered in case of food insecurity, or, in a context of poverty, if these supplements represent a less expensive option for providing all nutrients needed by children. The article by Saskia de Pee and Martin Bloem [4] presents several possible options.

Too many uncertainties were highlighted in this meeting to be able to propose an optimal diet for all children with moderate malnutrition in the short term. Enough information is available, however, to improve the current situation and to start a process of continuous evaluation and improvement of possible treatment options for moderate malnutrition. We hope this meeting will contribute to achieving these objectives, which are within our reach and will contribute to reaching Millennium Development Goals 1 and 4.

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Proposed recommended nutrient densities for moderately malnourished children

Michael H. Golden

Abstract

Recommended Nutrient Intakes (RNIs) are set for healthy individuals living in clean environments. There are no generally accepted RNIs for those with moderate malnutrition, wasting, and stunting, who live in poor environments. Two sets of recommendations are made for the dietary intake of 30 essential nutrients in children with moderate malnutrition who require accelerated growth to regain normality: first, for those moderately malnourished children who will receive specially formulated foods and diets; and second, for those who are to take mixtures of locally available foods over a longer term to treat or prevent moderate stunting and wasting. Because of the change in definition of severe malnutrition, much of the older literature is pertinent to the moderately wasted or stunted child. A factorial approach has been used in deriving the recommendations for both functional, protective nutrients (type I) and growth nutrients (type II).

Key words: Ascorbate, biotin, calcium, catch-up growth, cobalamin, convalescence, copper, DRV, essential fatty acid, folic acid, growth, iodine, iron, magnesium, malnutrition, manganese, niacin, nutrient density, nutrition, nutritional deficiency, nutritional requirements, pantothenic acid, phosphorus, potassium, protein, protein–energy malnutrition, pyridoxine, RDA, recommendations, riboflavin, RNI, selenium, sodium, stunting, sulfur, thiamine, vitamin A, vitamin D, vitamin E, vitamin K, wasting, zinc

Summary

The objective is to derive nutrient requirements for moderately malnourished children that will allow them to have catch-up growth in weight and height, prevent their death from nutritional disease, strengthen their resistance to infection, allow for convalescence from prior illness, and promote normal mental, physical, and metabolic development.

The malnourished population will have been exposed to nutritional stress and seasonal shortages and will have been living in unhygienic conditions; a proportion will have been severely malnourished. Typically, from 5% to 15% of children aged 6 to 59 months are moderately wasted, and 20% to 50% are stunted in height.

There has been little published on the requirements for the moderately wasted or stunted child *per se*. However, with the change in definition of severe malnutrition from the Wellcome classification [1] based upon weight-for-age to one based upon weight-for-height, reanalysis of the data shows that many of the studies of children with less than 60% weight-for-age included children who were moderately wasted by modern criteria, albeit stunted. The physiological and other data from the older literature therefore are likely to apply to those with moderate as well as those with severe wasting.

In order to derive the requirements of each nutrient for moderately malnourished children, the lower and upper boundaries were assumed to lie between the requirement for a normal, healthy child living in a clean environment and the requirement for treatment of a severely malnourished child living in a contaminated environment. The therapeutic diets used for treatment of the severely malnourished in the developing world have been remarkably successful and are capable of sustaining rates of weight gain of more than 10 g/kg/day and returning the children to physiological normality.

The requirements for normal Western individuals (Recommended Nutrient Intake, RNI) were used as the minimum requirements. They were converted into nutrient:energy densities with the use of the energy

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requirement for female children. The highest nutrient density among the various age categories of children was taken as a baseline.

For the growth nutrients (type II nutrients), a factorial method was used to determine the increment that should be added to allow for catch-up at 5 g/kg/day. To this increments were added to allow those with mild nondehydrating diarrhea to have their daily losses replaced and to have tissue deficits replaced over a period of about 30 days. For the type I nutrients (specific function nutrients), modest increments were added to cover the additional oxidative and other stresses that the subjects would be exposed to in unhygienic, polluted conditions; these include smoke pollution in the home, mild enteropathy, mild small intestinal bacterial overgrowth, some ingestion of fungal and other toxins arising from contaminated food and water, and recurrent infections such as malaria.

Two sets of requirements are suggested. First are the requirements for rehabilitation with the use of a variety of appropriately processed locally available foods; these are the minimum requirements, as it is unlikely that the optimal requirement for all nutrients can be consistently reached with unfortified local foods. Second are the optimal requirements proposed when special complementary, supplementary, or rehabilitation foods are being formulated to treat moderately malnourished children. It is assumed that these foods can be fortified with specific nutrients to achieve an optimal nutrient density for the moderately malnourished child.

Each nutrient is considered in turn and its peculiarities are considered. The nutrient:nutrient ratios were examined to ensure that the diet would not be unbalanced and that there would not be detrimental interactions between the nutrients.

The results are shown in **table 1**. The RNI values for healthy Western populations and the nutrient densities in the F100 formulation used for rehabilitation of the severely malnourished are also shown, as these represent the lower and upper boundaries within which it is expected that the values for most nutrients needed by the moderately malnourished will lie.

It should be emphasized that there are many uncertainties involved in deriving these first estimates of the

TABLE 1. RNIs for normal children, nutrient contents of F100 and RUTF (used for treating children with severe acute malnutrition [SAM]), and proposed RNIs for children with moderate acute malnutrition (MAM) living in contaminated environments, expressed as nutrient:energy densities (amount of nutrient/1,000 kcal)

Nutrient	Gravimetric unit	RNIs for normal children		F100 and RUTF for SAM	Proposed RNIs for MAM[a]				
		FAO	Other[b]		Food	Supplement	SI unit	Food	Supplement
Protein									
Protein	g	22.3	—	28.4	24	26	—	—	—
Nitrogen	g	3.6	—	4.6	3.9	4.2	mmol	275	300
Minerals									
Sodium	mg	—	978	434	550 maximum	550 maximum	mmol	24	24
Potassium	mg	—	1,099	2,400	1,400	1,600	mmol	36	41
Magnesium	mg	79	112	175	200	300	mmol	8.3	12.5
Phosphorus	mg	450	634	762	600	900	mmol	19	29
Sulfur[c]	mg	0	0	0	0	200	mmol	0	5.6
Zinc	mg	12.5	16.5	22.3	13	20	μmol	200	310
Calcium	mg	595	820	1,009	600	840	mmol	15	21
Copper	μg	—	892	2,749	680	890	μmol	11	14
Iron	mg	17.8	17.8	24[d]	9	18	μmol	160	320
Iodine	μg	201	201	190	200	200	μmol	1.6	1.6
Selenium	μg	17.8	29.7	55	30	55	nmol	380	700
Manganese	mg	—	1.2	0.69	1.2	1.2	μmol	22	22
Chromium	μg	—	10.8	0	0	11	nmol	0	210
Molybdenum	μg	—	16.6	0	0	16	nmol	0	170
Vitamins, water soluble									
Thiamine (vitamin B_1)	μg	523	523	700	600	1,000	mmol	2.0	3.3

continued

TABLE 1. RNIs for normal children, nutrient contents of F100 and RUTF (used for treating children with severe acute malnutrition [SAM]), and proposed RNIs for children with moderate acute malnutrition (MAM) living in contaminated environments, expressed as nutrient:energy densities (amount of nutrient/1,000 kcal) *(continued)*

Nutrient	Gravimetric unit	RNIs for normal children		F100 and RUTF for SAM	Proposed RNIs for MAM[a]				
		FAO	Other[b]		Food	Supplement	SI unit	Food	Supplement
Riboflavin (vitamin B_2)	µg	595	595	2,000	800	1,800	mmol	2.1	4.8
Pyridoxine (vitamin B_6)	µg	595	732	700	800	1,800	mmol	4.7	10.7
Cobalamin (vitamin B_{12})	ng	966	966	1,000	1,000	2,600	nmol	745	1,930
Folate	µg	167	167	350	220	350	nmol	500	795
Niacin	mg	6.4	8.4	10	8.5	18	µmol	70	145
Ascorbate (vitamin C)	mg	45	74	100	75	100	µmol	425	570
Pantothenic acid	mg	2.7	2.7	3	2.7	3	µmol	12.3	13.7
Biotin	µg	9.7	9.7	24	10	13	nmol	40	53
Vitamins, fat soluble									
Retinol (vitamin A)	µg	595	743	1,500	960	1,900	µmol	3.3	6.6
Cholecalciferol (vitamin D)	µg	7.4	10.9	30	7.4	11	nmol	19	29
Tocopherol (vitamin E)	mg	8.9	8.9	22	11.5	22	µmol	27	51
Phytomenadione (vitamin K)	µg	16.1	16.1	40	20	40	nmol	44	89
Essential fatty acids									
N-6 fatty acid	g	—	—	5	5	5	—	—	—
N-3 fatty acid	g	—	—	0.85	0.85	0.85	—	—	—
Others									
Choline	mg	—	223	—	223	223	—	—	—
Histidine	mg	—	430	—	430	430	—	—	—
Isoleucine	mg	—	575	—	575	575	—	—	—
Leucine	mg	—	1,245	—	1,245	1,245	—	—	—
Lysine	mg	—	1,190	—	1,190	1,190	—	—	—
Methionine + cystine	mg	—	575	—	575	575	—	—	—
Phenylalanine + tyrosine	mg	—	1,125	—	1,125	1,125	—	—	—
Threonine	mg	—	655	—	655	655	—	—	—
Tryptophan	mg	—	175	—	175	175	—	—	—
Valine	mg	—	776	—	776	776	—	—	—

FAO, Food and Agriculture Organization; RNI, Recommended Nutrient Intake; RUTF, ready-to-use therapeutic food

a. The recommendations for moderately malnourished children are divided into two components. The first component (Food) is the amount that should be in the diet when programs are based on a mixture of local foods to treat the moderately malnourished without general fortification of the diet. The second component (Supplement) is the suggested nutrient density that should be achieved in the diet when specially fortified supplementary foods are used in a program to treat moderately malnourished or convalescent children.

b. Highest of the values given by other authorities: see **table 45** for details.

c. The sulfur should be in addition to that derived from protein.

d. Iron is only added to RUTF, not to F100 nutrient requirements for the moderately malnourished. As new data become available, it is anticipated that the proposed nutrient requirements will be incrementally refined and expert opinion will converge.

The particular forms of the nutrients (salts and purity), which can affect taste, availability, dietary interaction, acid–base balance, efficacy, and cost, that should be taken into account in formulating any supplementary foods or fortification are considered. The effects of antinutrients that affect absorption and availability or directly damage the intestine, as well as a more detailed discussion of the essential fatty acids, are considered in the companion article by Michaelsen et al. [2].

A summary of the derived nutrient requirements is given in **table 1** expressed as nutrient densities (nutrient/1000 kcal). The derived nutrient requirements expressed in absolute units are given in the appendix (**table 46**).

Introduction

National and international RNIs are derived from experimental data from normal, healthy individuals living in a clean, secure environment and developing and growing normally.

In the developing world, most individuals do not live in such a clean, secure environment. One could argue that the RNIs do not apply to much of the world's population. In general, the environment is unhygienic; the children have recurrent infections, drink contaminated water, are exposed to smoke pollution from cooking fires, eat food containing fungal and bacterial toxins, and subsist on a limited range of crops grown in the immediate vicinity of their homes. Their growth and development are retarded. In such circumstances, it is likely that the requirements for nutrients are higher than for those living in safe, secure environments. The reality is that the diets of these children are much poorer than those of children living without such stresses, where food comes from a wide variety of sources. When they get an infection and lose their appetite, there is an acute loss of weight; this is so for all children in all societies. However, in impoverished households there is no subsequent catch-up growth during convalescence. The diets are of insufficient quality to replace the nutrients lost during the illness and to allow the children to return to normal. From 5% to 15% of the world's children are wasted (low weight-for-height), with the peak prevalence being between 6 and 24 months of age; 20% to 40% are stunted (low height-for-age) by the time they reach 2 years of age.

There are no internationally agreed RNIs for such children; although there have been published recommendations, there has been no justification for the levels chosen [3–5]. The Food and Agriculture Organization/World Health Organization (FAO/WHO) and the Institute of Medicine (IOM) have addressed this need in their reports but have not proposed any changes to the RNIs for such circumstances. However, agreed recommendations are needed in order to plan programs, treat moderate malnutrition, prevent deterioration, and assess the diets of those who are living in stressful environments or are at risk for malnutrition. The recommendations for healthy Western populations are based upon relatively extensive experimental data; these RNIs give a necessary benchmark from which to start [6–14]. However, for many essential nutrients, there are major gaps in the data upon which the RNIs are based. This is particularly true when deficiency in the West is not encountered in the healthy (e.g., potassium, magnesium, phosphorus) or the emphasis is on excess intake (e.g., sodium); these nutrients become critically important when there are abnormal losses from the body, for example, with diarrhea or enteropathy, and in the malnourished. Deficiencies of these same nutrients are usually reported by those caring for patients with gastroenterological disease or requiring parenteral nutrition. For many other nutrients, their bioavailability from the complex matrix of foodstuffs commonly consumed where malnutrition is common is unknown [15]. Furthermore, for children in the age group from 6 to 59 months, there are few direct experimental measurements, and RNIs have been assessed either by extrapolation from older age groups or from the composition of breastmilk [16]. The resulting judgments for normal children differ from committee to committee, sometimes quite dramatically.

Children who need to replenish the tissues that have been lost while developing moderate malnutrition or who need to have catch-up growth during convalescence from illness will have higher requirements for nutrients laid down in growing tissue than normal children. Children living in hostile environments will also require higher intakes of "protective" nutrients than those who are not under stress. Normal children gain weight and height at a slow pace relative to other mammals; thus, the increments in nutrient intake required for growth over those required for maintenance in the normal child are quite modest. However, the malnourished child will need to grow at an accelerated rate to catch up. In these circumstances, the requirement for growth becomes a higher proportion of the total requirement and the balance of nutrients changes; a richer, more nutrient-dense diet is needed to enable functional tissue to be synthesized more rapidly than normal.

General considerations in the derivation of RNIs for moderately malnourished children

The effects of giving modern therapeutic diets to severely wasted children are dramatic. The children regain their appetites and ingest enough of the diet to gain weight at up to 20 times the normal rate of weight gain; indeed, the Sphere Project standards require an average rate of weight gain of more than 8 g/kg/day [17]. However, with the older diets, when emphasis was placed upon energy density, the children did not regain physiological or immunological normality; thus, delayed hypersensitivity [18], thymic size [19], sodium pump function [20], glucose tolerance [21], renal concentrating ability [22], and muscle size [23] remained abnormal after treatment. Even though they gained weight rapidly and reached normal weight-for-height, they had a deficit of functional tissue and an excess of fat tissue; they were relatively obese [24–28] because the balance of nutrients was not correct to allow appropriate amounts of lean tissue to be synthesized. When the limiting "growth nutrient" was added to the diet, the children would regain more functional tissue and their physiology and immunity would improve [29–31], presumably until the next essential nutrient limited further growth. With the modern diets based upon the F100 formula, they regain physiological and biochemical normality [32, 33].

These observations raise a critical point. Weight gain, of itself, does not indicate a return to physiological, biochemical, immunological, or anatomical normality. Indeed, consuming "empty calories" that do not contain all the nutrients in the correct balance necessary to regain functional tissue results in the deposition of the excess energy as adipose tissue. In this way, an inadequate diet may well convert a thin, undernourished individual into an obese, *undernourished* individual*; this was often the experience with the older diets used to treat malnutrition and with attempts to treat stunted children with energy supplements alone [34]. Indeed, many overweight children are stunted in height, indicating that they have had a chronic deficiency of nutrients required for growth [35, 36]. We should not rely only on an observed rate of weight gain or final body weight-for-height when we judge the adequacy of diets or supplementary foods. It is likely that accelerated growth in height is a better indicator of nutritional adequacy for a child than weight gain.

Nevertheless, the composition of the modern diets for treating severe malnutrition (F100 [37–40] and the derivative ready-to-use therapeutic foods (RUTFs) [41]) gives a probable upper limit to the nutrient intakes that are likely to be required by the moderately malnourished or convalescent child living in a hostile environment.

Thus, for any new recommendations for the moderately malnourished, the requirements for most nutrients are likely to lie somewhere between the requirements for a normal child living in a clean, safe environment (the RNIs) and a severely malnourished child recovering in a hostile environment (F100 formula).

Variables determining the increments needed for the moderately malnourished child

The derivation of recommendations for the moderately malnourished to have catch-up growth depends upon five variables:

- The amount of new tissue that needs to be synthesized to achieve a normal body composition;
- The time available for the child to recover;
- The composition of the new tissue in terms of the ratio of adipose to lean tissue (and skeletal tissue) that should be deposited to achieve functional normality;
- The extent of any initial nutrient deficit or excess in the body tissues brought about by physiological adaptation to the malnourished state;
- Whether there are likely to be changes in nutrient availability due to intestinal abnormalities or ongoing pathological losses in the moderately malnourished child.

Each of these variables affects the desirable daily intake of the nutrients essential for replenishing and synthesizing new tissue. When individual nutrients are being considered, the effect of each of the variables needs to be examined.

Nevertheless, there are considerable uncertainties in attempting to derive nutrient requirements for the moderately malnourished child. Indeed, there are uncertainties in the derivation of the RNIs for normal, healthy children; for some nutrients, the extant data are not sufficient to set RNIs, and therefore Adequate Intakes (AIs), which are observed intakes of American children that have no apparent detrimental effect on health, are used. The uncertainties also include the degree of wasting and stunting that has to be corrected, the initial deficits of the tissues themselves and the body stores of nutrients that need to be corrected, the composition of the tissue that needs to be deposited, the rate of weight or height gain that is achievable (the length of time over which recovery should take place), and the effect of changes in intestinal function in children with moderate malnutrition on the absorption of nutrients from the diet, as well as the effect of intercurrent infections, diarrhea, accompanying chronic infections, and environmental pollution on nutrient requirements. Each of these factors is potentially of critical importance in determining the quality of recovery of the malnourished child and should be considered in setting requirements. However, reliable and quantitative data are lacking for many of these considerations. Thus, it is likely that there will be many points upon which experts' opinions diverge. The present article is deliberately conservative. For example, even if a

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* Obesity is only "overnutrition" in terms of energy. Obese individuals can be undernourished in terms of many essential nutrients; the empty calories are laid down as fat because energy *per se* cannot be excreted, but coincidental low intakes of essential nutrients results in many obese persons being undernourished. It is misleading to think of obesity as "overnutrition"; nutrition is much more than simple energy intake.

TABLE 2. Rates of weight gain required to catch up in weight over 14 to 40 days[a]

Category change		–3 to 0 z-scores	–3 to –1 z-scores	–3 to –2 z-scores	–2 to 0 z-scores	–2 to –1 z-scores	–1 to 0 z-scores
14 days	Male	16.9	11.1	5.5	11.4	5.7	5.8
	Female	18.3	12.0	5.9	12.4	6.1	6.3
20 days	Male	11.8	7.8	3.8	8.0	4.0	4.1
	Female	12.8	8.4	4.2	8.7	4.3	4.4
30 days	Male	7.9	5.2	2.6	5.3	2.6	2.7
	Female	8.5	5.6	2.8	5.8	2.9	3.0
40 days	Male	5.9	3.9	1.9	4.0	2.0	2.0
	Female	6.4	4.2	2.1	4.4	2.1	2.2

a. The rates of weight gain are expressed in g/kg/day, using the mean body weight as the denominator. The values are the means for children from 60 to 85 cm in height; within this height range, the maximum and minimum divergence of values ranged from 0.7% to 2.5% of the quoted value, respectively. All calculations are based on WHO 2005 standards. [42]

mean rate of weight gain of 5 g/kg/day is not frequently achieved in a group of children under traditional treatment, there will be individuals within the group who will achieve greater rates of weight gain, and the current treatment itself may be limiting the rate of recovery. Thus, it is reasonable to set the requirements at levels that permit such a rate of recovery, and not to set them at levels that restrict the weight gain or physiological recovery of some of the children with moderate malnutrition. Similarly, for body composition, if the deficit is mainly of adipose tissue, then the nutrient density requirements for its replacement will be relatively modest, and giving a diet that is more nutrient dense will have no detrimental effect. On the other hand, if the deficit is mainly of functional tissue, setting the requirements at a level that would allow mainly for adipose tissue synthesis would fail to return some of the children to normality and might promote obesity. The RNIs, in the presence of such uncertainty, should be set at a level that will not compromise groups of children and yet are achievable both with mixtures of local foods and with fortified foods, where the fortification is not elevated to a level that would pose a hazard if the fortified food was taken exclusively. As with the RNIs for healthy children, setting the RNIs for malnourished children will necessarily involve value judgments and compromises to be made, but it must be understood that the degree of uncertainty is much higher than with normal, healthy children and the consequences of underestimating the requirements are more likely to lead to death.

As new data become available, it is anticipated that the proposed nutrient requirements will be incrementally refined and expert opinion will converge.

Rates of tissue accretion

The wasted child should be able to replenish both the lean and the fat tissues within a reasonable period of time to reach the normal range of weight-for-height. It is usual for these children to have several episodes of acute illness each year. If most children with moderate malnutrition are to regain normality before the next attack of acute illness, it is reasonable for such children to regain their weight deficit in 30 days or less. If the deficit is between –2 z-scores (just moderately malnourished) and –1 z-score (the lower limit of normal and the upper limit for mild wasting), then the rate of weight gain required will be less than if a child is to gain weight from –3 z-scores to achieve the median weight-for-height of 0 z-scores. The rates of weight gain required to achieve different degrees of catch-up over periods of 14 to 40 days are shown in **table 2**.

In general, girls need to achieve a slightly higher rate of weight gain than boys. Since the definition of moderate malnutrition is from –2 to –3 z-scores, for a child of –2 z-scores to become normal (0 z-scores) or a child of –3 z-scores to achieve –1 z-score over a period of about 30 days, the rate of weight gain will need to be about 5.5 g/kg/day.* For the purposes of making recommendations for the moderately malnourished child, the diet should be capable of supporting rates of weight gain of at least 5 g/kg/day.

Although lower rates of recovery for the moderately malnourished are often found in practice, it is unreasonable to set the recommendations at a level that would restrict the recovery of children because of an inadequate nutrient intake. On the other hand, it is desirable that recovery should take place with a mixture of locally available foods; if the target weight gain is excessive, this could be unachievable. If higher rates of weight gain (to achieve a shorter recovery period or a greater total weight gain) need to be achieved under special circumstances, then the nutrient composition of the diet should approach that of F100.

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* If the same table is constructed with the weight at 0 z-scores used as the divisor, then the corresponding figure is about 4.9 g/kg median z-score/day.

Energy cost of tissue synthesis

To determine the extra energy and nutrients required for new tissue synthesis at an accelerated rate, we need to know the nutrients and energy that are to be sequestered in the tissue and the energy needed to synthesize the tissue. Theoretically, fat has 9.6 kcal/g and adipose tissue is usually slightly less than 80% anhydrous tissue, so that the energy deposited in adipose tissue is about 8 kcal/g. The energy content of protein is 4 kcal/g.* Lean tissue contains between 18% and 20% solids,** and the rest is water. Thus, the energy deposited in lean tissue is about 0.8 kcal/g of tissue. It takes little energy to synthesize 1 g of adipose tissue, but to assemble 1 g of lean tissue requires about 1.0 kcal/g. Thus, 8 kcal/g are required to make adipose tissue and 1.8 kcal/g to make lean tissue. If mixed tissue is being made (half lean and half fat), then the theoretical energy required to make that gram of new tissue is 4.9 kcal/g. However, at least 10% of the diet is usually malabsorbed in the recovering malnourished child without diarrhea, so the ingested energy required to synthesize 1 g of mixed tissue is about 5.5 kcal/g.

In children recovering from severe malnutrition, this is the figure that has been determined experimentally in a number of studies (**table 3**), and the mean when a complete diet is given is also about 5 kcal/g of new tissue. In one elegant experiment in which the children's muscle mass was measured, Jackson et al. [44] were able to predict the proportion of newly synthesized tissue that was lean tissue by measuring the energy cost of weight gained. When the diet has a low density of an essential nutrient, the energy cost of tissue synthesis rises as more of the energy is deposited as fat (**table 3**). In one experiment using a diet deficient in zinc, the energy cost rose above that predicted if only fat was being deposited; this was due to the zinc deficiency itself causing intestinal dysfunction. As the zinc deficiency became more severe, energy was lost from the body by malabsorption. It should be noted that many of the reported studies of malnutrition were conducted before we understood the importance of nutrients such as zinc for the quality of the tissue synthesized. For the purposes of calculation of the requirements for tissue synthesis, a figure of 5 kcal/g can be used for general mixed-tissue synthesis. For individual nutrients, it is possible to calculate the requirements for different proportions of lean and fat tissue being synthesized, using the energy cost of fat and lean tissue synthesis separately. The energy cost of skeletal growth is unknown but is assumed to be low, since skeletal accretion is relatively slow.

It is important to note that the energy requirement is higher, and the essential nutrient requirement is lower, for adipose tissue synthesis than for lean tissue synthesis. Conversely, when lean tissue is to be synthesized, the energy requirement is relatively low and the nutrient requirement is high. In this way the nutrient density is a determining factor in the type of tissue that can be synthesized during catch-up growth: the nutrient density has to be sufficient to allow the child to regain physiological, anatomical, and immunological normality, while not depositing excess adipose tissue.

Stunting considerations

"Stunting" is a dynamic process. In order for a normal child to meet the criteria for moderate or severe stunting (< −2 and < −3 height-for-age z-scores, respectively), that child will have to have been growing at less than the rate of a normal child for some time. For example, if a normally grown 1-year-old child starts to gain height at only 70% of normal (i.e., that child is in the process of stunting), she will not fall below the cutoff point to be defined as stunted until 2 years of age [55]. This is why the stunted child is regarded as having "chronic malnutrition." Undoubtedly, most stunted children have been stunting for a long time. However, in the young child, growth in height is sufficiently rapid for a child to fall behind her normal peers quickly; she can also have accelerated height gain within a few weeks or months to catch up completely. At a population level, changes in mean height-for-age can be rapid and responsive to changing conditions. This is clear from the seasonal changes in the prevalence of stunting seen in some countries*** [56]. It is misleading to think of "stunting" as a chronic process; it is an active, cumulative, ongoing condition. Although stunting (the process) may be acute,

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* The Atwater factors, which are used to calculate metabolizable energy content of food, use 4 kcal/g for protein, because the urea that is excreted contains the residual energy from the protein. If the dietary energy intake is calculated with the use of bomb calorimetry factors instead of Atwater factors, then the energy content of protein is 5.6 kcal/g.

** The water content of lean tissue varies with the rate of growth or tissue synthesis. During rapid growth, the cytoplasm contains a higher proportion of low-molecular-weight osmolytes and the tissue is more hydrated. This is the reason that, for example, the muscle of a newborn is much more hydrated than that of an adult. The changes in hydration with growth rate in the malnourished are illustrated by the data of Patrick et al. [43]. This variable has not been taken into account in any of the calculations in this paper. Over the first few days of rapid growth, the energy cost of weight gain can be low because of the water accompanying the accumulation of low-molecular-weight anabolytes and glycogen.

*** In this study, it appeared that the children were gaining height and weight at different times of the year, so that with the gain in height, there was a fall in weight-for-height and an increase in height-for-age, and with the gain in weight, there was a gain in weight-for-height and a fall in height-for-age. It is likely that the seasonal change in diet quality was responsible for the differences in height and weight gain occurring at different times of the year. It is possible that the weight gain was mainly accounted for by adipose tissue without either lean tissue or skeletal tissue growth. Unfortunately, body composition was not assessed.

TABLE 3. Experimental studies on the energy cost of tissue deposition

Subjects and author	Cost (kcal/g tissue)	Date	Ref.	Country	Notes
Recovering children with SAM on milk diet					
Ashworth	5.5	1968	[45]	Jamaica	Milk diet—with K and Mg only
Kerr 1	4.61	1973	[46]	Jamaica	Milk diet—with K and Mg only
Kerr 2	6.2	1973	[46]	Jamaica	Milk diet—with K and Mg only
Whitehead	3.5	1973	[47]	Uganda	
Spady	4.4	1976	[48]	Jamaica	Milk diet—with K and Mg only
Jackson	6.1	1977	[44]	Jamaica	Only 5 subjects—but had muscle mass measured
Golden	4.8	1981	[29]	Jamaica	Milk diet—early in recovery, mixed tissue synthesized
Morris	5.1 ± 0.5	1989	[32]	Jamaica	Standard milk-based diet with added minerals
Morris	4.8 ± 0.5	1989	[32]	Jamaica	F100 diet
Recovering children with SAM on type II–deficient diet					
Waterlow	6.56	1961	[49]	Jamaica	Original diets—deficient in several nutrients
MacLean	8.39	1980	[24]	Peru	Nitrogen balance shows only adipose tissue being made
Golden	6.9	1981	[30]	Jamaica	70% fat tissue synthesis—low-Zn diet
Golden	8.1	1981	[29]	Jamaica	Milk diet—late in recovery with probable limiting nutrients, fat being synthesized
Recovering children with SAM on soy-based diet					
Golden	6.5	1981	[29]	Jamaica	Soy-based diet—early in recovery
Golden	7.4	1981	[29]	Jamaica	Soy-based diet—late in recovery
Golden	15.5	1991	[50]	Jamaica	Soy-based diet (high phytate, mineral deficient)
Golden	7.4	1991	[50]	Jamaica	Soy-based diet plus Zn
Normal children					
Fomon	5.6	1971	[51]	USA	
Payne	5	1971	[52]	Review	
Reviews (various subjects)					
Roberts	2.4 to 6	1989	[53, 54]	Review	

SAM, severe acute malnutrition

when a child is stunted (the end result), we can say that the process has been present for a long time. Perhaps it would be more appropriate to refer to the stunted child as having “persistent malnutrition” rather than chronic malnutrition.

In terms of examining the requirements for such children, it is useful to differentiate the process of failure to grow in height from the long-term outcome of having failed to grow in height for a considerable period. The adverse nutrition and environment of these children usually do not change, so the process is ongoing; the children are found in the community because persistent stunting is compatible with life. The older and farther behind the child is, the longer the child will have to maintain an accelerated rate of growth for full catch-up. Conversely, the earlier the age at which a child is identified to be stunting, the easier and more rapid is the reversal of stunting. For the older child, a stage may be reached where there is simply insufficient time remaining to make a complete and full recovery; however, studies of children whose circumstances have changed show clearly that the potential for catch-up remains until at least adolescence [55]. It is wrong to think that after the age of 2 or 3 years treatment is totally ineffective. However, for increased rates of height gain to be maintained over a prolonged period, a permanent change in the quality of the child’s diet is required; this is rarely the case, so that many observational studies show that the deficit acquired in early life does not usually change [57, 58]. To prevent stunting, this improvement must occur over the time the child is actively stunting, which is during the first 2 years of life. It is at this age that children are fed monotonously on traditional weaning foods, usually cereal paps of very low energy and nutrient density [59], and are less able to compete with siblings for food. Increasing the energy density alone has no effect on stunting but does increase the child’s fat mass [34]. Preventive intervention should be strongly focused on the young child, certainly below the age of 2 and preferably from birth, but treatment should be offered to all stunted children irrespective of their age.

Stunted children: Catch-up in height

The maximum rate of height gain that can be achieved by a stunted child receiving optimal provision of nutrients and otherwise without disease is not known. One way to consider what is biologically possible is to compare the absolute rate of height gain of young infants with those of older children. For example, a child growing from 2 to 3 months of age gains about 1 mm per day. If a 24-month-old child gained height at 1 mm per day, her height gain would be 3.5 times the normal rate for a child of that age. The "potential" computed in this way is shown in **figure 1**.

A wasted child, having catch-up weight gain, can lay down tissue faster than a normal child at any age*; absolute or relative rates of height gain above those of a young infant do not seem to have been documented in the child over 6 months of age. This may be due to a change in the Karlberg phase of growth [60]. However, it is reasonable to suppose that gain in height of a taller, older child could occur at the same absolute rate as in a shorter, younger child. Another way to examine the maximum potential for catch-up in height comes from Western children treated for growth-retarding diseases [61, 62]. Unfortunately, nearly all examples come from children over 24 months of age. However, older children with pituitary disorders treated with growth hormone, hypothyroid children treated with thyroxin, and children with celiac disease treated with a gluten-free diet all catch up, initially, at between three and four times the normal rate of height gain for their age [62, 63]. As these accelerated height gains are maintained for long periods of time, it is likely that even higher rates of height gain could be achieved over short periods of rehabilitation. Dramatic changes in height are also seen in recovering malnourished children, although they are sustained for relatively short periods of time and have not been properly documented. Children treated for trichuris dysentery syndrome and not given any particular nutritional supplement gained height at up to three times the normal rate [64]. For children recovering from shigellosis, Kabir et al. [65] reported that 33-month-old children (86 cm) gained 10.2 ± 4.4 mm (SD) during 21 days of convalescence. The average is about twice the normal (using WHO 2005 standards [42]) If we now take the mean plus 2 standard deviations (that is 10.2 plus twice 4.4 = 19 mm over 21 days), the rate of height gain was 0.9 mm/day, compared with a normal rate of height gain of 0.3 mm/day for children 86 cm in height (WHO 2005 [42]); it is even higher when compared with the normal rate of height gain of children 33 months of age. Thus, in Bangladesh, rates up to three times the normal rate of height gain were observed; given that these children were probably fed suboptimal diets with respect to the ratios of type II nutrients and that they were already 33 months old, this is likely to be a conservative estimate of what is possible in the younger malnourished child receiving an optimum diet. The extent to which seasonal changes in the prevalence of stunting are due to spontaneous catch-up in height at rates greater than normal is unknown; but if a child after 1 year has a normal height and has only been gaining height for one-third of the year because of seasonal shortages, the height gain during the 4 months of active growth will have been at three times the expected rate.

Thus, for the purposes of this analysis, it will be assumed that children over the age of 6 months have the potential to gain height at a rate that is at least three times the normal rate of height gain.

For children to catch up in height, they will need to have a sustained increase in dietary nutrient quality for sufficiently long to allow them to recover. **Figure 2** shows the number of days required to catch up either 1, 2, or 3 height-for-age z-score units if the child is gaining at between two and four times the normal rate of height gain for her age. A child under 1 year of age can gain 1 z-score unit in 2 to 4 weeks. The severely stunted (–3 height-for-age z-scores) 6-month-old child could fully return to normal height-for-age (0 z-scores) in about 6

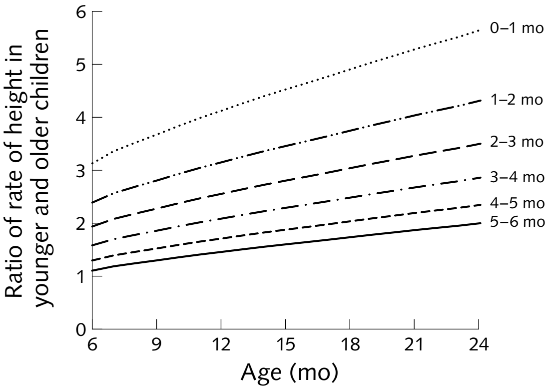

FIG. 1. Possible potential for catch-up in height. The absolute height increases of children from birth to 6 months, in 1-month intervals, were derived from the WHO 2006 standards. These were compared with the absolute monthly increases in height of children from 6 to 24 months. The graph shows the ratio of the absolute height gains (mm/mo) of younger to older children. For example, if a 24-month-old gained height at the same rate as a 0- to 1-month-old, she would gain height at 5.6 times the normal rate for her height and for her age (dotted line); if she gained height at the same rate as a 5- to 6-month-old, she would gain height at twice the normal rate for her height and age (solid line)

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* Up to 20 times the normal rate of weight gain for a child of the same age or height.

weeks. A 12-month-old child can catch up 1 z-score unit in about 3 weeks and fully catch up in height in about 2 months.

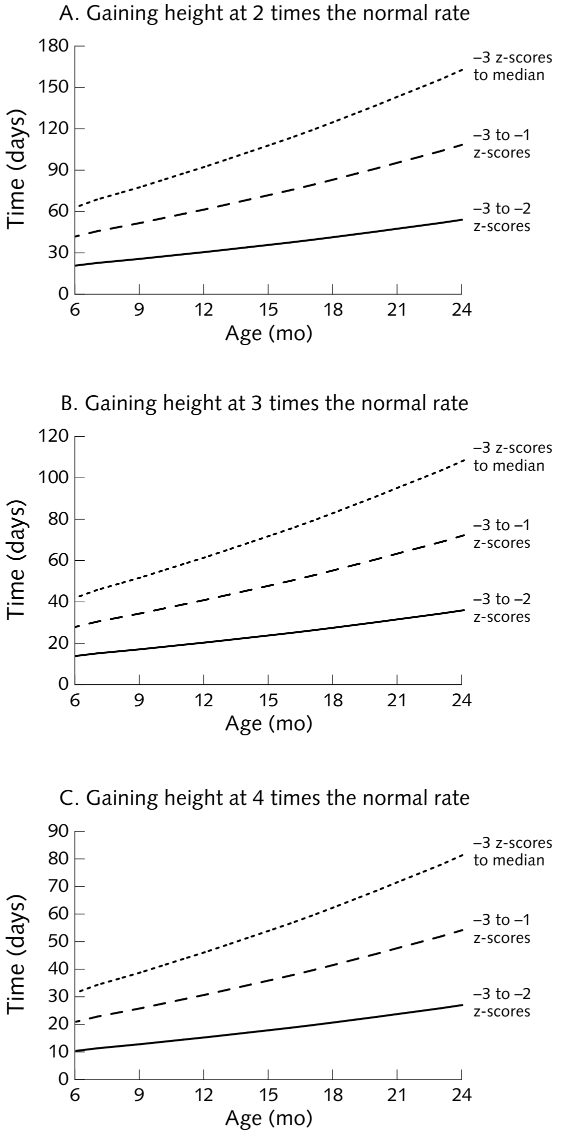

FIG. 2. Number of days it takes for children to gain 1, 2, or 3 z-score units in height if the rate of height gain is two (A), three (B), or four (C) times the normal rate (WHO 2005 standards) for children between 6 and 24 months of age. The time to gain 1 z-score unit (i.e., from −3 z to −2 z, from −2 z to −1 z, or from −1 z to the median height for age) is almost the same and can be read from the solid lines in the graphs for children gaining height at different rates. Similarly, the dashed lines give the time to gain 2 z-score units. For example a 6-month-old child catching up height at three times the normal rate will gain 2 z-score units of height-for-age in 28 days, and a 24-month-old child will take 72 days (dashed line in B)

Thus, although "stunting"[*] is often termed "chronic malnutrition," it should not be thought that its reversal in the young child requires prolonged intervention. However, to prevent the process of stunting from continuing will require a sustained change in the child's usual nutrition.

Thus, young children have the potential to catch up in height quite rapidly. Height deficits should no longer be thought of as "untreatable" within the time frame children are usually under therapeutic care. Rapid catch-up in height is frequently seen in practice when modern therapeutic diets are used to treat severe wasting. About 10% of children do not reach the weight-for-height criterion for discharge but remain in the program because their height increases at a sufficient rate for the children to fail to reach the weight-for-height discharge criteria; their weight is "chasing" the increasing height (unpublished data). If they remained in the program, presumably they would fully reverse their stunting as well as their wasting.[**]

A child who is stunted, but not wasted, and who catches up in height at an accelerated rate will need to have an associated increase in rate of weight gain if she is to remain at normal weight-for-height. Thus, when the nutritional requirements for height gain are considered, the requirements for the associated lean tissue accretion need to be included with any particular nutrient needs for bone and cartilage formation. In effect, the reversal of stunting requires "accelerated normal growth" and not "stretching" of the child, so that in gaining height there is a reduction in weight-for-height. If this happened, an increase in height could cause a child with normal weight-for-height to become moderately wasted, despite the fact that the child was actually growing at an accelerated rate. This is occasionally seen in practice. It may occur when children are gaining height, because their diet becomes richer in growth nutrients but lower

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[*] There is a problem with nomenclature in English. The term "stunting" is a verb denoting an ongoing process, and yet it is applied to the child who is already "stunted" (a noun representing the state of the child). Confusion between the process and the end result occurs because of this unfortunate nomenclature. "Stunting" is here used in the conventional, rather than the correct, way.

[**] The data of Golden and Walker [66] that suggested that children only gained height after they had reached their target weight-for-height were based on children who were being treated with the older diets that did not contain the full range of balanced nutrients that the modern diets contain. In this respect, the results reported in this study should be disregarded. The weight gain of these children was due to an excess of adipose tissue and insufficient functional tissue; they failed to gain height until they had recovered to normal weight-for-height and took a mixed diet. This is not seen with modern diets based upon the F100 formula. Measurements of wasted children recovering on F100 show that they start to gain height at about the same time as they start to regain weight (Bernabeau, Grellety, and Golden, unpublished), and that height gain is sustained after discharge for at least several weeks.

in energy so that they "exchange" adipose tissue for lean and skeletal tissue [34]. Seasonal differences in weight and height growth can be explained in this way [56, 67].

In order to examine the nutrient requirements for the reversal of stunting,* the height deficit, the time available for accelerated height gain, and the rate of weight gain that should accompany the height gain need to be considered.

Figure 3 shows the rate of weight gain that should accompany accelerated height gain. A child who is in the process of reversal of stunting also needs to gain weight at an increased rate. A child 6 to 9 months of age who is gaining height at three times the normal rate will need an average weight gain of 4 g/kg/day to maintain weight-for-height. This is close to the weight gain derived for moderately wasted children catching up in weight alone, and higher than that reported from some programs of home treatment of severely wasted children.

Thus, although there are no data to address the question of the different nutrient requirements for stunted and wasted children directly, most malnourished children have both wasting and stunting. It is desirable that both abnormalities be reversed by the nutritional treatments. We should focus on the requirements for normal growth at an accelerated rate, rather than considering whether there are different nutrient requirements for ponderal and longitudinal growth.

Diets that do not produce height gain in children who are both stunted and wasted probably do not contain the appropriate amounts of the essential nutrients required for the balanced accretion of tissue needed to regain normality. Although weight gain is frequently simply a result of a positive energy balance without adequate lean tissue synthesis, height gain is unlikely to occur without the necessary nutrients to make skeletal tissue, synthesize accompanying lean tissue, and allow for an appropriate and healthy hormonal and synthetic metabolic state. A gain in height is a better indicator of the adequacy of a diet than a gain in weight.

Are specific nutrients needed for reversal of stunting?

An increase of 1 cm in height should be accompanied by a weight gain of about 210 g.** To what extent are the nutrients sequestered in the new skeletal tissue different from those in the new lean tissue, and what are the relative proportions? Is a different balance of nutrients required for skeletal tissue and lean tissue formation? Or, more correctly, will the nutrients needed to synthesize 210 g of balanced soft tissue change substantially if there is also 1 cm of skeletal growth? For most nutrients, this seems unlikely. The exceptions may be those nutrients that are particularly concentrated in bone and cartilage: calcium, phosphorus, sulfur, and probably magnesium. For other nutrients, if the requirements for bone formation are the same as or lower than those for soft tissue formation, the needs for accelerated longitudinal growth can be ignored.***

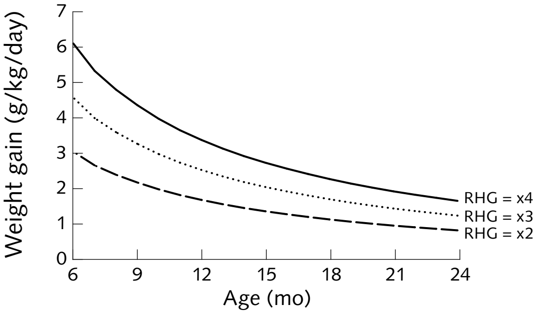

FIG. 3. Rates of weight gain that need to accompany accelerated height gain to maintain normal body proportions (weight-for-height). Based upon WHO 2005 standards. RHG, rate of height gain

The nutrients specifically required for skeletal growth are those that are in high concentration in cartilage and bone. Skeletal growth depends initially upon cartilage synthesis, followed by maturation and ossification of the cartilage and then remodeling of the osteoid of the mineralized cartilage. The nutrients needed for cartilage synthesis at the growth plates are thus the crucial factor in determining whether there is to be nutritional limitation of skeletal growth.

Cartilage is composed mainly of glycosaminoglycans such as chondroitin sulfate. These are highly branched carbohydrate chains attached to a small protein core. The characteristic of the carbohydrates moieties is that they are highly sulfated. The main essential nutrient needed in abundance to make cartilage is sulfur.**** Inorganic sulfate can be used; however, most of the sulfate in the body is derived from catabolism of the amino acids

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* With regard to various deficits in weight-for-age seen in many populations, regression analysis of weight-for-age against weight-for-height and height-for-age shows statistically that about 80% of the variance in weight-for-age is accounted for by the degree to which the children are stunted and about 20% of the variance by the degree to which they are wasted. Low weight-for-age is thus dominated by the stunting component of growth.

** For a girl between 60 and 85 cm in height, 1 cm of height gain is accompanied by a weight gain of between 183 and 253 g. A stunted child 6 to 24 months of age who has a deficit of 1 cm in height has a weight deficit of about 210 g (175 to 241 g).

*** This presumes that the nutritional requirements for hormone and growth factor formation are being met for normal lean tissue synthesis, in particular the requirements of vitamin D, iodine, and essential fatty acids.

**** In animal studies, bone growth is measured by the incorporation of radioactive sulfur into skeletal tissue [68, 69]. These assays, when used for factors in blood that stimulate bone growth, show low levels of these factors in malnourished children [70].

methionine and cystine.* Thus, there needs to be either adequate protein, relatively rich in sulfur amino acids, or inorganic sulfate in the diet to permit height gain. The other nutrient essential for normal cartilage maturation is vitamin D.

Bone is composed predominantly of phosphorus and calcium. The scaffolding is mainly collagen, which contains a low proportion of essential amino acids (less than that of the lean tissue accretion accompanying skeletal growth), so that the specific amino acid requirements for bone collagen synthesis can be ignored. However, vitamin C and copper are essential cofactors for the maturation of collagen. Vitamin K is required for osteocalcin to "capture" calcium during bone formation. Magnesium is essential, both for the synthesis and secretion of calcium-regulating hormones, and as a constituent of bone itself. Thus, the specific nutrients that are potentially needed in higher amounts for skeletal than lean tissue growth include sulfur, phosphorus, calcium, magnesium, vitamin D, vitamin K, vitamin C, and copper.

The effect of nutrient deficiency on bone growth is illustrated by the classic experiments of McCance and Widdowson [71]. Their research shows three pigs born from the same litter. The large pig was given a normal diet, the smallest pig a restricted diet, and the medium pig was given a protein-deficient diet. The growth of the lower jaw of the protein-deficient pig has grown normally, whereas the rest of the bones are short. The jaw bone is formed directly from the periosteum and does not require prior cartilage formation, whereas the leg bones require cartilage synthesis. It appears that protein deficiency has not caused a restriction of bone formation *per se,* as the jaw is normal, but has had a specific effect upon cartilage growth. This is most likely due to sulfur deficiency.**

In terms of ossified tissue, where calcium is the dominant nutrient, research by Hammond et al. shows the tibia and fibula of a feral pig, living wild, and the bones of a domestic pig from New Zealand (they are genetically similar, since there are no native wild pigs in New Zealand) [72]. The bones from the domestic pig are heavier and contain more calcium than the bones from the feral pig, but the feral pig's bones are longer. Calcium deficiency does not affect longitudinal growth. Calcium-deficient animals grow normally but have thin, weak bones. In contrast, growth ceases in animals with phosphorus deficiency. Even though calcium may not be important in stunting, children with moderate or severe malnutrition have thin, demineralized bones. Many have costochondral junction swelling, a sign of defective bone mineralization. This is likely to be due to either calcium or phosphorus deficiency.

Classification of the essential nutrients

About 40 nutrients are essential for health; each of them has to be in the diet that is supplied to children. If any one is not present in an adequate amount, the child will not be healthy, will not grow normally, will not resist disease, and will not convalesce satisfactorily from illness. If they are all important for the health and well-being of a normal Western child, each one is likely to be critical for children who are living under conditions of environmental and infective stress and who have persistent or acute malnutrition. Essential nutrients are classified according to the response to a deficiency [59, 73]. Type I nutrients are those that are needed for particular biochemical functions in the body. If these nutrients are severely deficient, the child will develop specific symptoms and signs of deficiency; if their level is suboptimal, the child will be less healthy and will be susceptible to stress and infection. However, deficiency of these nutrients does not generally lead to growth failure, at least not until the deficiency results in overt clinical illness. Thus, children who are classified as of normal weight or even overweight, on the basis of weight-for-height, height-for-age, weight-for-age, or mid-upper-arm circumference (MUAC), may have quite severe deficiencies of any of the type I nutrients. Although this undernutrition can lead to death, the children are not classified as "malnourished" because they have no anthropometric abnormality. Similarly, provision of adequate amounts of these nutrients will not lead to reversal of anthropometric malnutrition, but it will improve health and immune function. Deficiencies of several of these nutrients (iron, iodine, vitamin A) can be detected by convenient clinical features and tests, and therefore these nutrients have received most attention. For deficiencies of other type I nutrients, there are no pathognomonic clinical features and biochemical tests are inconvenient or expensive, so that deficiencies of these nutrients are frequently unrecognized until they are severe and life-threatening or cause an unfavorable outcome from intercurrent illness.

The type II nutrients are the growth nutrients. They

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* If these amino acids are in limited supply, they are likely to be consumed first for protein synthesis; then by the liver for synthesis of taurine, a component of bile salts, and for excretion of those toxins and metabolites that are eliminated as sulfates; and last, by the skeletal tissue to make cartilage. It is partly for this reason that gain in height presupposes the presence of sufficient sulfur-containing amino acids in the diet to fully satisfy these other essential nutrient requirements; height gain is also a better measure of nutritional adequacy than weight gain from this standpoint.

** The protein-deficient pig is also almost hairless. Hair proteins contain a high proportion of sulfur amino acids. There is disproportional growth failure in the different bones of stunted children. Among children who are stunted in height, the long bones are most affected, the spine is less affected, and the facial bones are least affected. Tooth formation is usually normal. This change in body shape is different from that seen in other causes of short stature, such as deficient secretion of growth hormone. The relatively short legs of the stunted may lead to underdiagnosis of wasting based upon weight-for-height measurements, and measurements of sitting height and leg length should be performed.

are the building blocks of tissue and are necessary for nearly all biochemical pathways. With deficient intake of any one of these nutrients, the child will not grow. A mild deficiency leads to stunting; with a more profound deficiency, or more commonly a pathological loss of the nutrient, there is also wasting. Because all tissues need these nutrients for cellular division and growth, those tissues whose cells turn over rapidly are most vulnerable. The enterocyte of the intestine has a life span of about 3 days, and some of the immune and inflammatory cells also have life spans of only a few days; therefore, a type II deficiency may aggravate or cause malabsorption and immune dysfunction. Because the moderately malnourished child (anthropometrically) has not grown, by definition there is a deficit* of *all* of the type II nutrients. This holds irrespective of whether the catabolic episode is due to an infection, a pathological loss, a specific type II nutrient deficiency, another cause of loss of appetite, or starvation. Since there are no body stores of these nutrients, apart from the functional tissues,** during tissue catabolism all the nutrients released from the tissue are lost from the body [75]. During treatment they *all* have to be replaced in balance if they are to be used efficiently for new functional tissue synthesis. This is the basis for the modern diets used to treat severe malnutrition; the same principles apply to moderate malnutrition, convalescence from illness, or any other condition that requires growth at an accelerated rate.

However, since children with moderate malnutrition (stunting or wasting) have normally been consuming a diet deficient in many nutrients, including both type I and type II, multiple deficiencies are common. It would be inappropriate to give only the type II nutrients in an attempt to reverse wasting or stunting and ignore the high prevalence rates of many of the type I nutrient deficiencies.

There has been an unfortunate tendency for medical researchers to give nutrients one at a time to observe whether they have an effect; the current fashion is to give zinc pills in the hope of finding the simple magic bullet. The history of parenteral nutrition provides a salutary lesson. One nutrient after another was "discovered" to be important for human health as they were added one-by-one and successive patients presented with deficiency of the "next" limiting nutrient. No animal or farm study would be carried out in this way. If one wanted to see the effects of a particular nutrient deficiency, every known essential nutrient would be given in what was thought to be adequate amounts, so that the diet was optimal, and then the nutrient of interest would be reduced or omitted to observe the specific effect. The same principles have to be applied to treatment of the malnourished. All essential nutrients have to be in the diet in adequate amounts to support health; if we are uncertain about the necessity of a particular nutrient, the correct procedure is to ensure that the amount that is currently thought to be optimal is in the diet. To examine the requirement for type II nutrients for the malnourished, the amount could be reduced incrementally until the accelerated growth rate slowed. Simply giving energy, protein, iron, iodine, vitamin A, or, more recently, zinc will not return malnourished children to full health. It was once thought that there would be sufficient adventitial zinc in most diets; that was false. Many people still consider nutrients such as pantothenic acid, biotin, essential fatty acids, or choline to be of little relevance; the devastating outbreak of irreversible neurological damage from pantothenic acid deficiency among refugees in Afghanistan should not have happened [76].

In deriving the requirements for moderately malnourished children, all nutrients known to be essential have to be considered, and the diets should contain sufficient quantities to restore full health. This was the principle behind the development of F100 and derivative foods used to treat severe malnutrition so successfully, and more recently to treat and prevent malnutrition in vulnerable populations [77]. It would be preferable to treat and prevent malnutrition with a mixture of local foods; if this is not possible, there will need to be some fortification or supplementation to ensure adequate nutrition for the moderately wasted and stunted.

Most populations have seasonal shortages and changes in their diets, so that the prevalence of malnutrition fluctuates quite markedly with the time of year. The children usually have depleted stores of type I nutrients (iron, vitamin A, riboflavin, etc.) and will have lost weight from a diminished appetite with low intakes of energy and type II nutrients. They are likely to have, or to recently have had, diarrhea. The moderately malnourished, therefore, do not start at the same baseline as those who are anthropometrically normal within the same population.

Anthropometric data on malnutrition have been used to calculate that about half of all child deaths are due to malnutrition [78]. These deaths are due to acute or persistent deficits of the type II nutrients. However, there are also widespread deficiencies of type I nutrients, such as vitamin A, iodine, iron, riboflavin, folate, vitamin B_{12}, and selenium, that are not causally associated with anthropometric changes but do cause death. Thus, another implication of the classification of nutrients into type I and type II is that the deaths from

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* It is useful to differentiate a "deficit" from a "deficiency." A deficit denotes not having enough of the nutrient in the body whereas a deficiency is a correctable cause of a deficit. For example, an energy deficit can be caused by anorexia due to zinc deficiency [74]; similarly, a potassium, magnesium, or phosphorus deficit can be caused by protein deficiency [75].

** For most of the nutrients, there are small "labile pools" that may function physiologically to buffer the effects of intermittent fasting and feeding over a few hours.

type I nutrient deficiencies (where there is no associated type II deficiency) need to be *added* to the deaths attributable to type II nutrient deficiency to derive the total mortality due to underlying nutrient deficiency.

Data on children with moderate malnutrition

There are few articles specifically addressing the functional* and nutritional deficits of the moderately malnourished or stunted child. However, the criterion used for diagnosis of severe malnutrition at the time when many studies were reported was either the Gomez or the Wellcome classification. The diagnosis of severe malnutrition at that time was less than 60% weight-for-age.** Many of the subjects of these studies were stunted. With the sequential revision of the way we define moderate wasting to less than 70% weight-for-height and then to −3 weight-for-height z-scores, much of the data published on "severe malnutrition" included a large proportion of children who would now be classified as having moderate wasting rather than severe malnutrition. For example, reanalysis of the weights and heights of marasmic children studied at the Tropical Metabolism Research Unit (TMRU), Jamaica (1980–90), and reported as "severely malnourished" shows that 61% had moderate wasting (< −2 to > −3 National Center for Health Statistics [NHCS] weight-for-height z-scores) and only 39% had severe wasting; when the same children were reassessed with the use of the WHO 2005 standards, 29% were still classified as moderately wasted. These children were severely stunted (60% < −3 z-scores, 32% < −4 z-scores, 16% < −5 z-scores). The same confusion about the definitions of "severe" and "moderate" malnutrition occurs even in recent publications (e.g., El Diop et al., 2003 [80], where half the severely malnourished children would be classified as moderately malnourished on the basis of weight-for-height). Thus, there is a considerable amount of information about the moderately wasted (and also stunted) child, which has not been reported separately from the data on the severely wasted child. For this reason, it would be safe to assume that the moderately wasted child has many of the physiological, immunological, and other features reported in the literature as "severe malnutrition" when weight-for-age has been used to classify the children.

Examination of some of the physiological data, e.g., renal excretion of acid after an acid load [81] or cardiac output [82], shows that the moderately wasted children lie between the recovered children and the severely wasted children. However, there is considerable overlap between the degree of functional abnormality of moderately and severely wasted children.

Thus, it is proposed that the effects on weight-for-age criteria of physiological changes reported for children diagnosed as having severe malnutrition should be taken into account when assessing the nutrient needs of the moderately malnourished. From this point of view, the diets should be closer to those formulated specifically for, and used successfully in, the severely malnourished child, than the requirements derived for normal children in a clean environment. Since most of these children are "uncomplicated" metabolically, they will have similar metabolic adaptations [83] to those reported. There is likely to have been an ascertainment bias toward children with complicated malnutrition on admission in the series reported from hospitals. Most experimental studies do not include the acutely ill children for ethical reasons; the children are studied after they have recovered from acute infections and other major complications. Thus, it is proposed that the increments added because of the initial tissue deficits should be included in the assessment of the requirements of the moderately wasted child. This proposal is speculative and is not based upon either direct measurements or reanalysis of archival data.

Energy requirements

The absolute amount of wholesome food that a normal individual eats is determined primarily by his or her energy needs: when there is an energy deficit, the person feels hungry,*** and when sufficient energy is consumed, the person feels satiated. It is remarkable how precisely energy balance is maintained, even in the obese gaining weight (if an adult gains 5 kg in 1 year, energy intake and expenditure are balanced to within 2%). The variation in individual energy intake over time is much less than the uncertainties in the other constituents of the diet. The foods that are chosen to satisfy energy needs depend upon tastes learned from the mother during pregnancy and the family in infancy, modulated by taste appreciation, habituation, organoleptic properties, tradition, culture, and learned feelings of well-being associated with different foods

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* An exception is the mental and behavioral development of malnourished children where the retardation is related to the degree of stunting rather than wasting.

** Usually using the Harvard standards published in earlier editions of *Nelson's Textbook of Paediatrics* [79].

*** Provided there is no major metabolic disturbance, such as liver disease, acute infection, or type II nutrient imbalance, all of which lead to anorexia. A low food intake because of such anorexia is often taken to represent an energy deficiency, rather than a deficit caused by some other factor. A low energy intake can be due to a deficiency in many other nutrients giving rise to anorexia. Anorexia does not need to be major to lead to malnutrition. If mild anorexia leads to an energy intake of 90 kcal/kg/day and the requirement is 100 kcal/kg/day so that the shortfall is 10 kcal/kg/day, the child will lose about 2 g/kg/day (5 kcal/g). In 10 days, 2% of body weight will be lost, and in 3 months, the child will have lost 20% of body weight and will now be classified as moderately malnourished (assuming no physiological adaptation). A tiny increment in anorexia over this time period will lead to severe malnutrition and a high risk of death.

and aversions associated with coincident illness.

If the quantity of food a person eats is closely related to energy requirements (at any particular level of adaptation), that total quantity of food has to contain all the nutrients for health. If "empty calories" form a large proportion of the diet, it is likely that the foods that make up the remainder of the diet will not be sufficiently nutrient rich to maintain health. This phenomenon of "eating to satisfy energy needs" is one of the principal reasons that we should use nutrient density as the main way of judging diets and specifying nutrient requirements. Simply adding oil to make a diet energy dense may have the effect of diluting all the essential nutrients: it does not prevent stunting [34]. A good diet is characterized by the consumption of a wide variety of different foods, with each food providing a different blend of nutrients. A highly varied diet is most likely to provide all the essential nutrients. A poor diet is characterized by large quantities of nutrient-poor staple food, restriction of diversity, and incredible monotony. This is particularly so for infants after weaning who are then given nothing but dilute traditional cereal porridge repeatedly at each meal. As a diet becomes more and more monotonous, the probability of there being a deficiency of any one essential nutritional component rises exponentially. There is no single natural food that is complete in all the nutrients needed to maintain health in the long term.* As a diet becomes more restricted, the balance of nutrients that is contained within the remaining few items must more nearly approach the ideal balance; such "ideal" foods are not commonly available.

Suppose a diet is composed of two foods, each forming half the diet, one of which is devoid of nutrient X, say a local staple, sugar, or oil, and the other is perfectly balanced, say a blended complementary or relief food; then the diet *as a whole* will contain only half the required amount of nutrient X, and the person will become deficient in that nutrient. This problem can limit the impact of food programs using "perfect foods" and accounts for the deficiencies in some infants who consume traditional weaning foods as well as breastmilk. Even adding oil (relatively "empty calories") can cause nutrient deficiency. If one substantial item is insufficiently dense in a nutrient, it must be compensated by a dietary item that is correspondingly more nutrient dense than required. In order to have a complete diet, it would be necessary to increase the nutrient content of some items in the diet to compensate for the impoverished state of the remainder of the diet. There is an example of this problem. Adolescents were given 100, 200, or 300 kcal/day as biscuits that were nutritionally deficient in several type II nutrients. The supplement was detrimental for the adolescents, with a negative "dose" response, those receiving 300 kcal being the worst. Presumably, the home diet was marginal in these nutrients, and adding a biscuit that displaced a proportion of the normal diet led to a reduction in the overall intake of the nutrients missing from the biscuit and thus had a detrimental effect on the health and well-being of the pupils [85].

There is an important corollary of this concept. If only two foods are consumed and they each have the appropriate nutrient density to fully satisfy the nutrient requirements if consumed exclusively, then the nutritional requirements of the child will be fully met with *any* admixture of the two foods. For example, if only breastmilk** and a fully fortified complementary food of appropriate nutrient density and bioavailability are consumed, then it does not matter what proportions of each food comprise the diet—it will be adequate. If this is the case, and the complementary food does not interfere with the availability of nutrients from the breastmilk, there could be a smooth change in the proportions of breastmilk and complementary food consumed by the infant, which will vary from infant to infant, without there being any nutritional deficit.

Use of energy as the reference point for determining nutrient requirements

Using energy as the reference point has sometimes been suggested by those making dietary recommendations [86, 87]. However, none of the committees have published recommendations based upon nutrient densities for their major RNI reports, although the WHO report does convert some of the nutrient requirements into densities in an annex [86]. Usually energy requirements are given separately for male and female children, but nutrient recommendations combine the sexes; there are often differences in the age ranges used for the RNIs and energy requirements and between different authorities.

Energy requirements are set at the mean intake necessary for a certain age or physiological category to maintain energy balance and for normal growth in children; there is an assumed Gaussian variation of

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* Even human breastmilk has low levels of iron and copper. This is not at all harmful, since physiologically the fetus accumulates stores of these nutrients to maintain supplies until weaning (premature infants may need supplements because the physiological mechanisms have been interrupted by the premature delivery), possibly to prevent intestinal infection [84]. Many moderately malnourished children have had either prematurity or intrauterine growth retardation; the additional requirements for those nutrients that have fetal stores and low breastmilk concentrations for this particular group of moderately malnourished infants are not considered in this report. The concentrations of other type I nutrients in breastmilk vary with the mother's status. The nutritional requirements of the lactating mother to enable her to provide milk with optimal amounts of nutrients are not considered in this report.

** Note that, as stated before, this argument does not apply to iron or copper because of the low levels in breastmilk.

individual requirements around this mean requirement. The RNIs are quoted in absolute amounts that will satisfy the physiological requirements of at least 97.5% of the population within a particular age and sex group. However, the actual requirements of both energy and each nutrient (say nutrient X) for each individual vary within the population. If the requirements for energy and nutrient X vary completely independently, then to cover 97% of the population's requirements, when these requirements are expressed as nutrient:energy densities (amount of nutrient X per kilocalorie), it would be necessary to increase the observed variation of the nutrient requirement to account for the additional variation due to the spread of energy requirements. Unfortunately, in the experiments that have been done to determine the requirements of nutrient X, simultaneous measurements of energy balance have not been reported. For this reason, it is unknown whether a person in the lower tail of the distribution for energy requirements is also in the lower tail of the distribution for all the essential nutrients.

In order to justify the use of nutrient densities (nutrient:energy ratios) in the design of diets for the moderately malnourished, the following were considered:

1. The absolute nutrient requirements are given for an age class. Within this age class, there will be physically smaller and larger individuals. A physically smaller individual is likely to have a lower requirement for both energy and nutrient X than the larger individual within that age class. When recommendations are made for a specific *age* group, this source of variation is taken into consideration and contributes to the variance used to make the recommendation. The moderately malnourished are smaller and lighter than the standards, to a variable degree, rendering recommendations based upon age inappropriate.
2. For individuals of the same weight, most of the variation in requirements is due to differences in body composition. Thus, the difference between male and female requirements is largely due to females' having a higher percentage of their body weight as fat. Fat has lower requirements of energy and all other nutrients for maintenance than lean tissue; thus, with a higher proportion of the body as fat, all the nutritional requirements, when expressed per kilogram of body weight, are lower. Bone, muscle, and skin, in turn, have lower maintenance requirements than the viscera. The variation in body composition is the major reason why different individuals have different nutrient requirements. Because infants have a much higher proportion of their body weight as highly active tissues (brain and viscera) than adults, they also have much higher energy and nutrient requirements per kilogram of body weight. There is substantial variation in body composition within any one weight class. Such variation is likely to affect both energy and nutrient needs in the same direction and perhaps in similar proportions, so that expressing nutrient needs in relation to energy requirements will automatically compensate for these differences. The moderately malnourished child (wasted or wasted and stunted) has a lower proportion of body weight as fat and muscle and a higher proportion as viscera and brain. Thus, the malnourished child would require more energy and nutrients per kilogram of body weight if there were no metabolic adaptation. This is sometimes found in practice in stunted children [88], despite presumed metabolic adaptation [83].
3. The basal metabolic rate is the major determinant of energy requirements. It varies from one individual to another, depending upon body composition and physiological state. As physiological state changes, the needs for both energy and each nutrient are likely to change in parallel. With an increased rate of tissue turnover, replacement, or repair, consumption of both nutrients and energy increases; with adaptation to a chronically low intake, tissue turnover decreases [89]. To set requirements per unit of energy automatically compensates for such changes in metabolic state, as the malnourished child goes from an adapted hypometabolic state with relatively low requirements to a hypermetabolic state with active anabolism during recovery. Both energy and nutrient intake will increase as the appetite increases. Setting requirements per unit of energy is more appropriate than setting RNIs in absolute amounts for these children based upon either age or weight criteria, as it takes the metabolic status of the child into consideration.
4. The energy requirements are clearly related to changes in physical activity. It is argued that the variance in basal metabolic rate itself covaries with the requirements for other nutrients. Does physical activity affect the irreversible disposal of nutrients as well as energy? As physical activity increases, there are increases in losses, and therefore in requirements, of many nutrients, most frequently demonstrated by increases in urinary nitrogen with exercise. There are insufficient data on the exact nature of the changes in needs for energy and most other nutrients with changed physical activity, and what data there are come from adult athletes and not children or the malnourished. It may be that the incremental need for energy is somewhat higher than the incremental need for other nutrients. Nevertheless, most energy is consumed for basal and resting metabolism, and the variation in physical activity level between people is relatively small. A discrepancy would not have a major effect upon the nutrient requirements when expressed as a nutrient:energy density. The malnourished are unlikely to engage in extreme physical activity.

5. In children and the convalescent, there are also energy and nutrient requirements for growth. The increment in nutrients required for new tissue formation is likely to be higher than the increment in energy required to achieve that growth. In normal children growing at a normal rate, the proportion of energy that is consumed for growth is a relatively small proportion of the total energy intake after 6 months of age. However, the relative amounts of energy and nutrients needed for growth are likely to be quite different from those needed for tissue maintenance. This becomes the critical issue for children who need to gain weight and height at accelerated rates. Furthermore, the relative energy and nutrient intakes required to support accelerated growth depend upon the type of new tissue that should be synthesized to return the child to normal. If the child is to make predominantly adipose tissue, the energy requirement will be high and the nutrient requirement will be lower; alternatively, if the child is to make lean tissue, the energy requirement will be relatively low and the nutrient requirement will be higher.

Much of the remainder of this article deals with the calculation of the increments in energy and nutrients needed to maintain increased growth while making balanced tissue.

Nutrient:energy density requirements for normal people

In order to compute the nutrient:energy density requirements, the following data were used:

- The FAO/WHO 2004 energy requirements [8];
- The WHO/FAO/UNU 2007 Protein requirements [90] ;
- The FAO/WHO/UNU 1985 Protein requirements [91];
- The FAO/WHO 2001 Human Mineral and Vitamin Requirements [7];
- The IOM series of publications [9–14]. The age ranges used for the IOM reports are not the same as those for the FAO/WHO requirements;
- The UK Dietary Reference Values (DRVs) 1991 [92]. Typical weights are given for the population groups.
- WHO/FAO/International Atomic Energy Agency (IAEA) 1996 for several trace elements [6].

For all calculations, the FAO/WHO 2004 energy requirements [8] have been used, with appropriate adjustments for the age ranges the different documents use. The energy requirements for children are given separately for males and females, whereas the RNIs for the nutrients are given as a combined figure. For the purposes of calculation, the energy requirements of females have been used. Since these are slightly lower than the male child's energy requirements, the derived nutrient:energy ratio is marginally higher when calculated with the use of the female energy requirement.

For previous estimates of nutrient densities needed for stressed populations, either the old factorial data [3] or the values of the International Dietary Energy Consultancy Group (IDECG) [93] were used [4, 5]. Although the IDECG figures are lower than those derived before the doubly labeled water technique was used exclusively, they are still higher than the present estimates of energy requirements; this change in the denominator has resulted in an *increase* in the nutrient density required in a diet to satisfy the nutrient requirements.

For each of the nutrients, the nutrient:energy density for young children was computed and expressed as the amount of nutrient required per 1,000 kcal of diet. The resulting values are presented in **table 45** (see appendix).*

When there are major discrepancies between the different bodies that have made recommendations, those of FAO/WHO have been preferred. When other bodies have set higher values, the reasons for the choice have been examined in the original documents: if the reasoning of the committee is both cogent and applicable to a deprived population, these values are considered. In general, the FAO/WHO 2001 and the IOM recommendations are in agreement and are based upon more extensive and up-to-date experimental data; they also take into consideration the prevention of more subtle forms of deficiency, such as effects upon the immune system, the need for adequate antioxidant defense, and maintaining biomarkers within the physiological range.

Are the nutrient:energy density requirements derived for normal Western people applicable to the malnourished?

The conclusion is that the variations in requirements within a normal population are largely due to differences in body weight, body composition, and physiological state so that there is a direct relationship between the requirements for energy and most nutrients. These RNIs, when expressed as densities, can then be applied directly to the malnourished. The RNIs for maintenance and normal rates of growth for a child of the same height should relate directly to the stunted child if that child is to gain height and weight at the rate of a normal child, but only when they are expressed as nutrient densities, not in absolute amounts in relation to either height or age. If the child is to have accelerated

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* When expressed as nutrient:energy densities, requirements are similar across the age groups from children to adults [4]. Thus, for nearly all age groups, and pregnant and lactating women, the increments in nutrient and energy requirements are about the same proportionately. The conclusion is that the same food can be eaten and fully satisfy the nutrient needs of the whole family.

weight and height gain, increments will need to be added to the nutrient density to allow for the increased rates of tissue synthesis.

An important advantage of expressing the nutrient needs per unit of energy, instead of in absolute amounts, is that when the foods comprising the diet are taken to satisfy the appetite, and the energy requirements of each individual are satisfied, then all the nutrient requirements will automatically be met for that individual, no matter what the body composition or physiological state, and the same requirements will apply to males and females. However, if an individual is moderately malnourished and needs to have catch-up growth, the increment in energy required for catch-up growth will be less than the increment in nutrients if the tissue is to be mainly functional, lean tissue. There are data from recovering severely and moderately wasted children. As the child with severe malnutrition gains weight, he or she quite quickly passes to the stage of being moderately wasted and then normal. The nutrient densities found to be so successful for the severely malnourished child are clearly adequate for the recovery of moderately wasted children. In terms of new tissue accretion, the critical factors are the rate and type of new tissue that needs to be synthesized and not the degree of malnutrition (severe, moderate, mild, or convalescent) the child has initially; the same principles and calculations apply to each condition. The difference between the groups is the length of time that the increased rate of weight and height gain has to be sustained. Thus, if one wanted a moderately malnourished or convalescent child to recover very rapidly, the same diet as that used for the severely malnourished child would be appropriate, and we could use the nutrient balance represented by the F100 formula; if the appropriate rate of tissue accretion is less rapid, then a diet that is less nutrient dense could be used. In other words, the nutritional composition of F100 is also appropriate for moderately malnourished or convalescent children, particularly if it is expected that a further infection or other circumstance will curtail the length of time available for recovery.

Going from recommendations for a healthy population to a population with a baseline of nutritional deficiency and moderate malnutrition

In deriving the requirements, no attempt will be made to provide therapeutic amounts of nutrients to rapidly reverse overt nutrient deficiency. The recommendations are not designed for treatment of clinical deficiency. Nevertheless, it is desirable for the recommended nutrient densities to be enriched over and above that required to maintain a healthy Western population living in a conducive and relatively hazard-free environment. The RNIs, as nutrient densities, need to be adjusted to make allowance for the following factors that are usual in most populations of children with moderate malnutrition:

» There is a reduction in the intestinal absorptive function of most people who live in poverty in a chronically contaminated environment. This is partly due to overgrowth of bacteria in the small intestine [94–102], which appears to be ubiquitous in the malnourished and present in all populations of such children who have been investigated. Most malnourished children spend a substantial proportion of their lives with at least mild diarrhea. This may, in part, be due to the prolonged high intake of lectins, saponins, and other antinutrients in the unrefined diet [103]. The levels of antinutrients allowable in foodstuffs have not been established by the *Codex Alimentarius*. This question is addressed by Michaelsen et al. [2]. The recommendations for nutrient intakes for the malnourished need to take into consideration reduced bioavailability from the typical matrices of a poor traditional diet. This is likely to be exacerbated by the reduced capacity of the moderately malnourished to absorb nutrients, the reduced levels of digestive enzymes [104, 105] and gastric acid [106], and the bacterial overgrowth and the increased vulnerability of such an intestine to antinutrients and naturally occurring toxic factors in foods. Bioavailability studies have not normally been conducted in subjects with such fragile intestinal function.

» These children are repeatedly exposed to infectious agents. In such conditions, it is important to ensure adequate intake of all the nutrients critical for the maintenance of the immune system. The children are also ubiquitously exposed to pollutants, particularly smoke from cooking fires [107–109]. There is a particular increase in the need for many of the antioxidant nutrients under conditions of both infection and exposure to pollution. For example, the IOM specifically increases the requirement of vitamin C for cigarette smokers, a cause of oxidative stress; such stress may also underlie the anemia associated with the use of biomass as fuel [110].

» The diets of most poor people are predominantly vegetarian. Because of the fiber and phytate within these foods, there will be a low bioavailability of several divalent cations (Ca, Mg, Zn, Fe); of equal importance, phosphorus will be deficient (phytate is the storage form of phosphorus for the plant—inositol hexaphosphate—and if it is lost in the feces, the available phosphorus will be lower than needed). Seeds have the correct nitrogen:potassium:magnesium:phosphorus ratio to make cytoplasm for the growing plant. If the phosphorus is malabsorbed because it is in the form of phytate, the balance of absorbed type II nutrients needed to make cytoplasm will be incorrect and the other nutrients will be used inefficiently. If the culinary methods for food preparation do not release phosphate from phytic acid (e.g., fermentation, germination, and use of plant ash), the requirement for nutrients such as phosphate should be expressed in terms of *nonphytate* phosphorus. Nearly all food-composition tables give only total phosphorus for plant foods. However, up to 80% of this phosphorus is in the form of phytic acid and is potentially unavailable. To use total phosphorus in food composition tables is not adequate in terms of assessing foods to be included in the diet. Also phytate is a strong chelating agent for divalent ions—their requirement will need to be greatly increased from diets containing excessive phytate. Thus, there needs to be special consideration paid to mineral elements that have low bioavailability.

Given these constraints, the diet has to provide the additional nutritional requirements, in a readily available form, to effect rapid growth and recovery of malnourished, infected, and diseased patients in a polluted environment. Several million children have been successfully treated with the F100 milk-based formula, which sustains rates of weight gain of up to 2% of body weight each day. Such high rates of weight gain are attained after the existing tissue deficits are restored. These requirements are only in excess of those required by the moderately malnourished if the moderately malnourished are to recuperate at a slower rate than the severely malnourished. If the moderately malnourished are to regain weight at the same rate as the severely malnourished then the nutrient:energy densities of the F100 formula is also appropriate for these children. The F100 formula gives an upper limit to the nutrient density that has been tried and tested in the same environment in which the moderately malnourished live. For weight gain, there is clearly no need to have the intake of any of the nutrients higher than those provided by F100, provided that the availability from the matrix is the same as that in F100; there may be additional requirements for height gain.

Comparison of nutrient:energy densities

Table 4 shows the nutrient densities for FAO/WHO RNIs, other RNIs, and F100 and the differences between the RNIs for healthy children and the nutrient densities provided by F100.

All the values in the table are expressed per 1,000 kcal energy requirement (FAO) for a female child of the same age range given for the recommended absolute intake. The table shows the highest FAO/WHO value for any of the age ranges considered and the highest non-FAO/WHO value from the other sets of recommendations. The data from which this summary table is derived are given in **table 45** (see appendix).The increments of nutrient density in F100 over the highest RNI for healthy children range from negative to more than 300% but in general are about 80% above the FAO/WHO RNIs and about 60% above the RNIs set by other committees. Given the need for accelerated growth and the environmental stresses that these children are under, these increments appear reasonable.

Approach to estimating changes in nutrient density due to growth

In order to examine the extent to which growth affects the desirable concentrations of nutrients per unit energy, it is necessary first to examine the energy requirements for catch-up growth. The levels of the different nutrients are then similarly calculated, and the ratios of the total requirements (maintenance plus the additional nutrient needs for rapid growth) to total energy needs are computed. These calculations are performed both without provision for a prior deficit in nutrient and then again for the sort of deficit that has been found by analysis of biopsies of tissues of children with malnutrition (or in some cases, whole-body analysis). Because the data do not differentiate moderately wasted from severely wasted children, the figures for malnourished children using weight-for-age criteria have been used. Until specific data for the moderately wasted become available, this approach should ensure that the recommendations for them are not insufficient.

Figure 6 shows the total energy consumed for catch-up growth at different rates (grams of body weight gained per kilogram of initial body weight per day) when different types of tissue are being replaced in the body. At the left-hand side of the graph, 30% of the new tissue is lean tissue and 70% is adipose tissue, whereas at the right side of the graph, 80% of the new tissue is lean tissue and 20% is adipose tissue. When there has been weight loss leading to malnutrition, there is a loss of both fat and lean tissue; this is clear from pictures of malnourished individuals who have very little subcutaneous fat and whose muscle and skin* are wasted. During recovery to normal, both types of tissues have to be replaced. Measurements have shown that it is desirable to have a weight gain of between 50% and 70% of lean tissue, with the balance as fat.

It is reasonable to aim for moderately malnourished patients to gain weight at about 5 g/kg/day and for them to replace their initial tissue deficits over about 30 days.

The graph (**fig. 6**) has been drawn using the data obtained from experimental studies on children recovering from malnutrition: the requirement for energy is 82 kcal/kg/day and the absorption of energy is 90% of that ingested, so that the child needs to ingest 91

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* The skin is the largest organ of the body; it atrophies in malnutrition.

TABLE 4. RNIs for normal children compared with F100 formula diet[a]

Nutrient	RNI (FAO)	Other (IOM/UK/WHO)	F100 and RUTF	F100 minus FAO	% Difference	F100 minus other	% Difference
Protein (g)	22.3	21.2	28.4	6.1	*29*	7.2	*34*
Protein (%kcal)	8.9	8.6	11.1	2.2	*26*	2.5	*30*
Sodium (mg)	529 UK	978	434	−95	*−10*	−544	*−56*
Potassium (mg)	1,099 UK	2,934	2,403	1,304	*44*	−531	*−18*
Chlorine (mg)	—	1,467	1,831	—	—	364	*25*
Magnesium (mg)	79	112	175	96	*85*	63	*56*
Phosphorus (mg)	450	634	762	312	*49*	128	*20*
Calcium (mg)	595	820	1,008	413	*50*	188	*23*
Zinc (mg)	12.5	16.5	22.3	9.8	*60*	5.8	*35*
Copper (µg)	332	892	2,749	2,417	*271*	1,857	*208*
Iron (mg)	18	16	24	6.2	*38*	7.6	*46*
Iodine (µg)	201	193	188	−13.1	*−7*	−5.1	*−3*
Selenium (µg)	17.8	29.7	54.8	37.0	*125*	25.1	*84*
Fluorine (µg)	—	740	NA	—	—	—	—
Manganese (µg)	—	1,170	690	—	—	−480	*−41*
Chromium (µg)	—	10.8	NA	—	—	—	—
Molybdenum (µg)	—	16.6	NA	—	—	—	—
Vitamin B_1 (µg)	523	525	700	177	*34*	175	*33*
Vitamin B_2 (µg)	595	628	2,000	1,405	*224*	1,372	*218*
Vitamin B_6 (µg)	595	732	700	105	*14*	−32	*−4*
Vitamin B_{12} (ng)	966	864	1,000	34	*4*	136	*16*
Folate (µg)	167	147	350	183	*124*	203	*138*
Niacin (µg)	6,239	8,368	10,000	3,761	*45*	1,632	*20*
Vitamin C (mg)	45	74	100	55	*75*	26	*35*
Pantothenic acid (mg)	2.7	2.7	3	0.3	*12*	0.3	*12*
Biotin (µg)	9.7	9.7	10.0	0.3	*4*	0.3	*4*
Choline (mg)	—	223	—	—	—	—	—
Vitamin A (µg)	595	743	1,500	905	*122*	757	*102*
Vitamin D (µg)	7.4	10.9	30.0	23	*206*	19	*174*
Vitamin E (mg)	8.9	5.2	22.0	12	*231*	17	*321*
Vitamin K (µg)	16	40	40.0	24	*60*	0	*1*

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom; WHO, World Health Organization

a. All values are expressed per 1,000 kcal female FAO energy requirement. Italicized numbers indicate a unit change to percentage.

kcal/kg/day* [48, 111, 112]. If each gram of new lean tissue consumes 2.8 kcal and each gram of new adipose tissue consumes 8 kcal, then the equation for energy requirement is

$$\text{Energy} = [82+ (2.8 * \text{lean} + 8 * (1 - \text{lean})) * \text{RWG}] / 0.9 \text{ kcal/kg/day}$$

(see legend to **table 5** for detailed explanation of the equation). For example, if the rate of weight gain (RWG) is to be 5 g/kg/day and the tissue is 70% lean tissue, then the equation becomes

$$\text{Energy} = [82 + (2.8 * 0.7 + 8 * 0.3) * 5] / 0.9 = 115 \text{ kcal/kg/day}.$$

For each of the growth nutrients, similar equations were derived from the amounts needed to maintain body weight, and then the increments were added from the concentrations of the nutrient in lean and fat tissue. Additional increments were added to account for an initial tissue deficit that has to be replaced. These were then divided by the energy equation, using

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* The normal calculation for energy requirement for maintenance uses 100 kcal/kg/day of offered diet. This includes an increment to account for malabsorption (10%) and also for spillage (5% to 10%). No account of spillage is taken in any of the calculations, because the same proportion of energy and nutrients will be spilled. To obtain the amount of the final diet that should be offered to malnourished children, it is important to reinstate an increment for spillage.

the same proportions of lean and fat tissue and rate of weight gain.

The factors and equations used to calculate the requirements for the type II nutrients are given in **table 5**.

Estimation of individual nutrients' RNIs for moderately malnourished children

Type II nutrients

Protein

The protein energy content of breastmilk is about 15 g/1,000 kcal (6% of energy). This protein is perfectly balanced to meet requirements; however, a proportion is immunoglobulin A, which is not absorbed, so that the available protein is less than 6% of dietary energy. Using cow's milk protein, F100 contains 28 g/1,000 kcal (11.2% of energy). This is sufficient for rapid catch-up growth at over 20 g/kg/day during recuperation. As this is sufficient for intense anabolism, it is unlikely that a higher protein requirement is needed for skeletal growth, provided that the other nutrients are all present at a sufficient density.

The RNIs are shown in **table 6**. The definitions of the age groups used by different authorities in this and subsequent tables are given in **table 45** (see appendix).

The highest figure is 22.3 g/1,000 kcal (FAO 1985 [91]), which should cover 97.5% of normal children's requirements. More recently, WHO/FAO/United Nations University (UNU) [90](2007) have revised these figures drastically to conform to the IOM calculations. These requirements are between 20% and 33% lower than the 1985 figures. This appears to be based upon the lower maintenance requirements assumed in the 2007 report.

The *average* protein requirement for malnourished children needed for maintenance without growth is 0.6 g/kg/day [113]. This does not allow for any individual variation. Furthermore, with this intake, severely malnourished children cannot resynthesize liver proteins [114], indicating that this figure, derived from nitrogen balance data, is an underestimate of the true maintenance requirement. The minimum requirement for normal children is about 1.2 g/kg; this is the amount of protein supplied by F75, the diet used for severely malnourished children on admission. The protein content is about 20% (wet weight) in lean tissue [115] and 2% in fat tissue. During rapid weight gain, the additional protein is used to make new tissue with about 60% efficiency [116]. It is assumed that 90% of the protein is absorbed. To attain a rate of weight gain of 5 g/kg/day with 70% of the new tissue as lean tissue would require 23.3 g/1,000 kcal (9.2% of energy as protein). The parameters for the equation are given in **table 5**, and the results of these calculations are shown in **table 7**.

These calculations assume that the amino acid ratio of the protein source is sufficiently high and that the protein contains the essential amino acids in the appropriate balance to make new lean tissue. If protein sources of lower quality are used, a higher density of protein should be used.

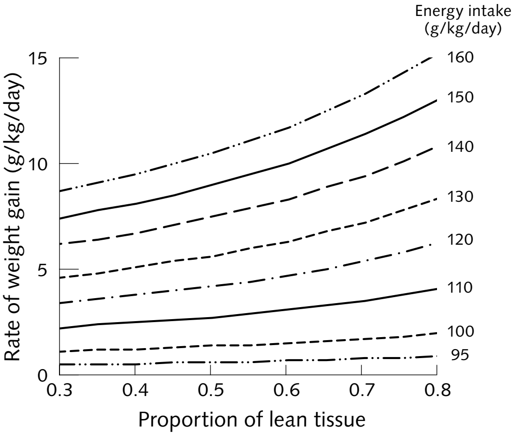

FIG. 6. Weight gain expected in relation to the proportion of lean tissue being synthesized for different energy intakes. For example, if a child is taking 140 kcal/kg/day and 80% of the new tissue is lean tissue, she should gain weight at 10.9 g/kg/day; if only 30% of the new tissue is lean and the rest is adipose tissue, the rate of weight gain should be 6.2 g/kg/day

In the past, increasing the protein content of diets and relief foods used in the treatment of malnutrition has not resulted in an increase in the rate of rehabilitation. This is thought to be because other type II nutrients have been limiting in these diets [117, 118]. When the diet is imbalanced, the excess protein will be broken down to energy and the nitrogen will be excreted.

It has been found that high-protein diets can be detrimental in severe malnutrition. This is thought to be for two reasons. First, whenever there is any compromise in hepatic function, additional protein that cannot be utilized for tissue synthesis has to be broken down by the liver and excreted; this process requires energy, which may be compromised in malnutrition [119], and generates an acid load [120, 121]. In experimental animals, a high protein load given in the presence of a dysfunctional liver can precipitate acute hepatic failure. When the protein cannot be adequately metabolized by the liver, a situation similar to an inborn error of amino acid metabolism occurs (malnourished children have acquired errors of amino acid metabolism [122–126]). Mild liver dysfunction is common in undernourished populations, particularly those that have been consuming aflatoxin-contaminated food, living on certain wild foods, or receiving herbal medicines. The second reason why it is unwise to have a high protein intake is the renal solute load that excess protein generates. Each gram of protein results in 5.7 mmol of urea. In countries where the climate is hot and dry, the water turnover can be up

TABLE 5. Summary equations used to derive energy and nutrient requirements for catch-up weight gain[a]

Nutrient	Unit	Maintenance (units/kg body wt/day)	Deficit increment (units/kg body wt/day)	Diarrhea increment (units/kg body wt/day)	Lean tissue (units/g tissue)	Adipose tissue (units/g tissue)	Efficiency of use (%)	Absorption (%)
Energy	kcal	82	0	0	2.8	8	100	90
Protein	g	1.2	0	0	0.2	0.02	60	90
Potassium	mg	70	18	47	3.6	0.4	100	90
Sodium	mg	10	−17.5	27	1.4	0.7	100	100
Magnesium	mg	14.4	4.8	7.2	0.24	0.024	100	30–60
Phosphorus	mg	34	14.5	68	1.86	0.3	100	60
Zinc[b]	µg	33	340, 570	110	81	8.1	100	15, 35, 56

a. The general form of the formula used was

Nutrient = [maintenance + deficit + diarrhea + ({(C-lean * P-lean) + (C-fat *(1 − P-lean))}*RWG)* efficiency] / absorption.

The units are energy or nutrient/kg/day.
Where:

Maintenance is the minimum amount of *absorbed* (not ingested) nutrient or energy needed for balance (units/kg/day). *Deficit* is the tissue deficit that has to be replaced *in the existing tissues of the body*, calculated from the measured reduction in tissue wet-weight concentration (usually from muscle biopsy) of the nutrient per kilogram (not adjusted for changes in body composition due to malnutrition) and converted into a daily additional requirement on the basis that the deficit in the child's existing tissue is to be made good in 30 days. That is (normal-concentration * deficit-proportion/30); for example, if the normal potassium level is 2,340 mg/kg and there is a 23% deficit, then the daily increment added for the deficit is 2,340 * 0.23/30 = 18 mg/kg/day. *Diarrhea* is the *additional* amount of the nutrient, over and above the maintenance requirement, that is lost when the child has one or two nondehydrating loose stools per day, converted into a daily loss per kilogram of body weight. *C-lean* is the concentration of the nutrient or energy in normal lean tissue (nutrient per gram of tissue). *P-lean* is the proportion of new tissue synthesized that is lean tissue. *C-fat* is the concentration of the nutrient or energy in adipose tissue. (*1 minus P-lean*) is the proportion of new tissue that is adipose tissue. *RWG* is the rate of weight gain (g/kg/day); this has been taken to be 5 g/kg/day for most analyses. *Efficiency* is a factor to allow for the efficiency of conversion of the absorbed nutrient into tissue. It is assumed to be 100% for most nutrients that are recycled in the body. This factor is only applied to the nutrient laid down in new tissue; it is assumed that a reduced efficiency is already incorporated into estimates of the maintenance requirement. How the efficiency changes with clinical state or in making good a deficit is unknown, and efficiency is therefore assumed to be 100%; if it were less, this would have the effect of increasing the nutrient requirement. *Absorption* is the proportion of the nutrient or energy ingested that is absorbed into the body (availability).

At any particular rate of weight gain and tissue composition, the derived value for the nutrient requirement was divided by the derived value for energy requirement (nutrient/kg/day divided by energy/kg/day = nutrient/energy) to obtain the nutrient:energy density; it was expressed as amount of nutrient per 1,000 kcal required in the diet of moderately malnourished children to promote rapid growth.

Most of the values in the table come from single studies in patients with a spectrum ranging from moderate to severe malnutrition. Many of these studies are old and use relatively inaccurate analytical techniques. The confidence intervals around the values, and hence the derived requirements, are correspondingly wide; see text under each nutrient for references.

b. Two figures are given for zinc deficit and three for availability. These represent different estimates of the deficit and the change in availability from diets of different matrices. See section on Zinc.

to one-third of body water per day [127]. A high-protein diet is a reason for a high water requirement and can even lead to hyperosmolar dehydration. Because both of these factors are exacerbated by diets that contain low-quality protein, it is necessary for the amino acid score of the diet to be at least 70% of the reference protein.

The FAO/WHO and IOM protein recommendations for normal children are 21 g/1,000 kcal and 22 g/1,000 kcal, respectively; F100 contains 28.4 g/1,000 kcal but is designed to sustain a higher rate of weight gain than that under consideration for the moderately malnourished. The present calculations suggest that an intake of high-quality protein of 23.3 g/1,000 kcal would be adequate for the moderately wasted or stunted child.

It is therefore proposed that the diet should contain 24 g of protein with a quality of at least 70% of reference protein per 1,000 kcal. A protein source with a lower amino acid score should not be used for the treatment of the moderately malnourished.

If supplementary foods are being formulated, it is reasonable to increase the total dietary intake to 26 g/1,000 kcal to account for the uncertainties of the calculations and any additional needs of stunted children. It is recommended that protein sources rich in the sulfur amino acids should be used preferentially in stunted populations.

The appendix (**table 45**) gives the amino acid requirements per 1,000 kcal for normal children. There are insufficient data to make recommendations for individual amino acids for the moderately malnourished child. Nevertheless, the nutrient density of essential amino acids in the diets of moderately malnourished children should not fall below the requirements for normal children.

Sulfur

There are important uses for amino acids beyond the synthesis of protein. In particular, the metabolite sulfate

TABLE 6. RNI protein requirements expressed as nutrient densities and proportion of energy

Unit	Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
g/1,000 kcal	FAO 1985	22.3	20.1	15.2	14.6
g/1,000 kcal	FAO 2007	15.0	15.6	12.8	13.5
g/1,000 kcal	IOM	—	16.4	12.7	13.7
g/1,000 kcal	UK	21.4	21.2	15.2	14.8
%kcal	FAO	8.9	8.0	6.1	5.8
%kcal	IOM	—	6.5	5.1	5.5
%kcal	UK	8.6	8.5	6.1	5.9

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

TABLE 7. Protein:energy ratio for children gaining tissue with between 30% and 80% lean tissue at different rates[a]

% lean	1 g/kg/day	2 g/kg/day	3 g/kg/day	5 g/kg/day	10 g/kg/day	15 g/kg/day
30	15.0	15.2	15.5	15.9	16.6	17.1
35	15.2	15.6	16.1	16.8	18.0	18.7
40	15.4	16.1	16.6	17.6	19.4	20.5
45	15.6	16.5	17.2	18.5	20.8	22.3
50	15.8	16.9	17.8	19.4	22.3	24.2
55	16.0	17.3	18.4	20.3	23.9	26.2
60	16.3	17.7	19.0	21.3	25.5	28.4
65	16.5	18.2	19.7	22.3	27.2	30.6
70	16.7	18.6	20.3	23.3	28.9	32.9
75	16.9	19.0	20.9	24.3	30.8	35.4
80	17.2	19.5	21.6	25.4	32.7	38.0

a. Note that with low rates of weight gain and 30% lean tissue deposition, the ratio approximates that of the IOM calculations.

is used to synthesize 3’-phosphoadenosine 5’-phosphosulfate (PAPS). This is the high-energy sulfate compound used to make glycosaminoglycans for basement membranes and cartilage. The sulfate is derived mainly from the amino acids cystine and methionine. There is experimental evidence that addition of inorganic sulfate can alleviate some of the requirements for these amino acids, in both animals and humans [12], and sulfate added to a protein-deficient diet can result in a growth response. On the other hand, excess sulfate in the diet is not absorbed and can give rise to an osmotic diarrhea (magnesium sulfate is used as a laxative). The average intake of sulfur from all sources by children up to 5 years of age in the United States is between 0.5 and 1.5 g/day [12], which is high in comparison with the IOM requirement for sulfur amino acids of 575 mg/1,000 kcal; this equates to about 170 mg of sulfur per 1,000 kcal.

There may be a particular requirement for additional sulfate in stunted children, since they will require accelerated cartilage synthesis. If additional sulfate is not taken in the form of protein, there should be adequate inorganic sulfate in the diet.

There is a further reason why sulfur-generating amino acids are important in a hostile environment. Many relatively hydrophobic toxins and drugs are eliminated by conjugation with sulfate in the liver for elimination in the bile. Other xenobiotics and products of free-radical damage are covalently bound with the sulfhydryl moiety of glutathione and eliminated in the urine as mercapturic acids; their excretion is elevated in the malnourished child [128]. If there is a high exposure to such toxins (smoke, food toxins, and bacterial products), additional sulfur-containing amino acids, over and above those needed for protein and glycosaminoglycan synthesis, need to be supplied.

Low levels of sulfate are excreted by children on a typical African diet [129] and those with malnutrition [130, 131], and these children have undersulfation of glycosaminoglycans [132–134]. Adequately sulfated glycosaminoglycans may be particularly important to prevent viral infection [135, 136]

Because of the additional needs for cartilage synthesis in the stunted child and toxin elimination in those living under stressful conditions, it is suggested that the diet of these children should contain additional sulfate. The amount is uncertain but is clearly an important research topic. **It is suggested that about 200 mg of sulfur per 1,000 kcal, as sulfate, be incorporated in the diet, *in addition* to the sulfur that is present in the form of amino acids.** This is likely to be particularly important in stunted populations.

Potassium

There is considerable uncertainty about the potassium requirements in normal people. For this reason, most committees have omitted setting RNIs or AIs for potassium, even though it is a critical essential nutrient. This is partly because normal dietary intake in the West is thought to greatly exceed the minimum requirement and because the homeostatic mechanisms for conserving potassium are very efficient in a healthy population, so that deficiency is nearly always associated with pathological losses or physiological adaptation. The healthy do not get potassium deficiency; the diseased do.* In particular, there is a major depletion of potassium in all malnourished patients [137–146]. The early studies, based upon weight-for-age definition of marasmus, show that this applies to both moderate and severe malnutrition. Potassium is critical in the management of malnutrition; it has even been suggested that the administration of heroic amounts of potassium lowers mortality** [147]. Some committees have suggested minimum intakes or AIs for Western populations. The uncertainly is reflected in the marked difference in the published figures (**table 8**). The 10th edition of the US Recommended Dietary Allowances (RDAs) [148] gives minimum values of 800 to 1,000 mg/1,000 kcal. The UK safe allowance is 1,100 mg/1,000 kcal. The recent IOM recommendations are considerably higher than this, going up to nearly 3 g/1,000 kcal for a 1- to 3-year-old child. The IOM figure is very high and is in disagreement with all other estimates of the requirement in normal children. The report states that the AI is based upon little scientific evidence and is mainly set to "mitigate the effects of a high sodium intake." It is above the level of potassium used in F100. This number will therefore be ignored in setting the recommendations for the moderately malnourished, and the UK figure of 1,100 mg/1,000 kcal will be used.

The amount of potassium in F100, 2,400 mg (61 mmol)/1,000 kcal, is adequate to replete body potassium in the severely malnourished in about 2 weeks [149] and support rapid weight gain. Thus, this amount could be considered as the upper boundary for the moderately malnourished. No tolerable upper limit has been determined for potassium in any of the publications, but a proportion of children have impaired renal function in malnutrition [22, 81, 150–154]; high levels of potassium are dangerous in many forms of renal disease, and it would be unwise to give excess potassium to these children.

Because potassium is critical for the maintenance of cellular physiology and is required in substantial amounts for convalescent growth and for those with mild diarrhea or other illness, it clearly has to be incorporated in adequate amounts in the diets of the moderately malnourished, even though the requirements for the normal, healthy Western person are so uncertain.

In assessing the amount of potassium that is required the following factors need to be taken into account:

Normal potassium losses. On a diet containing 780 mg (20 mmol) of potassium per day, adults lost 10,000 mg (250 mmol) of potassium from their bodies, and some of the subjects had subnormal plasma potassium concentrations. Therefore, this intake was inadequate to meet obligatory losses, even though after the subjects had lost this amount of potassium they adapted to regain potassium balance [155] (despite considerable sodium retention and alkalosis [156]). The minimum daily fecal losses were about 400 mg (10 mmol), and the renal losses were 200 to 400 mg (5 to 10 mmol). Such experimental deficiency studies have never been performed in children.

In malnourished children *without* diarrhea, but with an adequate potassium intake, the stool output was 23 ± 10 (SD) mg/kg/day (0.6 ± 0.25 mmol/kg/day) [157]. These children all had low total body potassium content and could be said to be "adapted" in a similar way to Squires and Huth's adults [155]. This would then perhaps give a minimum stool output with an upper 97.5% limit of 43 mg (1.1 mmol) per kilogram of body weight per day.

The minimum urinary losses are unknown. Normally about 3% of filtered potassium is excreted, which corresponds to about 1,000 mg (26 mmol) per day in a normal adult and correspondingly less in a child in relation to the body surface area. The losses in the urine of normal Western children range from 27 to 90 mg/kg/day (0.7 to 2.3 mmol/kg/day), which is consistent with the figure in adults when converted to body surface

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* Potassium deficiency is especially likely in patients with diarrhea, diuretic-induced renal losses, anorexia, and any abnormalities of the sodium pump or cell membrane, such as those present in moderate and severe wasting.

** There is one report that severely malnourished children have a better outcome with the administration of higher amounts of potassium [147], but the baseline mortality was high with all diets that were being used in this study; if this was due to excess sodium administration, it would account for both the high mortality and the unexpected beneficial effects of exceptionally large amounts of potassium. There is the potential for hyperkalemia and cardiac effects when very large amounts of potassium are given. This appears to have been the situation when the wrong measure was used to add mineral mix to the diet of children recovering from malnutrition in Kivu, Democratic Republic of the Congo, resulting in an increased potassium intake.

TABLE 8. Potassium AIs (mg/1,000 kcal)

Nutrient	Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
Potassium	IOM	—	1,041	2,934	2,737
Potassium (min)	UK	1,099	1,001	818	821

AI, adequate intake; IOM, Institute of Medicine; UK, United Kingdom

area. It is reasonable to assume that the lower bound of this range corresponds with the minimum amount of potassium that is desirable to have available to excrete in the urine to allow for flexibility of homeostatic adjustment for health. Sweat and other losses are trivial compared with fecal and urinary losses.

It is therefore desirable to have sufficient potassium, at a minimum, to maintain a renal excretion of 27 mg (0.7 mmol)/kg/day and a fecal excretion of 39 mg (1.0 mmol)/kg/day, giving a *minimum* requirement of 66 mg (1.7 mmol)/kg/day for children without diarrhea.

Pathological losses. The diet is for malnourished children where there is a high prevalence of diarrhea and tropical enteropathy. It is reasonable to take this into account when formulating the requirements.

Potassium is the major cation in normal feces; it is exchanged for sodium mainly in the colon. In diarrhea this exchange is less than perfect, so that with increasing volume of diarrhea the sodium concentration increases and the potassium concentration decreases [158, 159]. Although the concentration of potassium may decrease, this is more than offset by the increased volume of diarrhea, so that there is a substantial increase in the amount of potassium lost in all forms of diarrhea. Indeed, it is not until the volume of stool approaches that typical of cholera that the electrolyte concentrations approach those seen in the extracellular fluid. In modest diarrhea there is equimolar potassium and sodium, and in normal stool potassium reaches 90 mM concentration. Thus, although the mean stool potassium output of a malnourished child without diarrhea was quite modest, with one or two loose stools (which are usual in malnourished children) the output increased to 62 ± 23 mg (1.6 ± 0.6 mmol)/kg/day [157]. In acute diarrhea the output can be considerably higher. Ruz and Solomons [160] published an equation for children with diarrhea, which indicates that the output is related to fecal volume by the relationship

$$\text{Potassium (mg/kg/h)} = 3.11 + 0.96 * \text{fecal volume (mL/kg/h)}.$$

The average weight of each diarrheal stool from a malnourished child of 6 kg is about 30 g; if a child has two such stools per day (not sufficient to be diagnosed as acute diarrhea), there will be a loss of 10 g/kg/day of stool, and the fecal output of potassium will increase to 90 mg/kg/day for replacement. It should be noted that the large increment in this equation goes from normal stool to a watery stool; the increment per stool is more modest. Dehydrating degrees of diarrhea should be treated with rehydration therapy; the dietary recommendations do not cover such needs. Nevertheless, two "loose stools" that do not result in dehydration or cause the parents to seek help will result in an additional potassium loss that must be made good from the diet. This is common in the moderately malnourished.

Thus, the potential requirements to cover the needs of the malnourished child (without any pre-existing potassium deficit) with mild diarrhea that is not severe enough to require special treatment are shown in **table 9**.

The effect of growth. It is usually assumed that there are major additional requirements for potassium during convalescence requiring weight gain. The potassium content is about 3,590 mg/kg (92 mmol/kg) in muscle and about 350 mg/kg (9 mmol/kg) in fat tissue, so that the total body potassium content is about 2,340 mg/kg (60 mmol/kg).

The increment in energy requirement over the basal requirement is greater than the increment in potassium requirement over the basal requirement, so that with synthesis of new tissue the nutrient density falls marginally. Therefore, the effect of growth on the requirement for potassium relative to energy in the diet can be ignored in setting recommendations for the moderately malnourished.

The type of tissue does make a difference. When lean tissue is being synthesized, much more potassium is needed than when adipose tissue is laid down. At rates of weight gain up to 5 g/kg/day, the increment is much less than the uncertainties in the values used for tissue deficit, stool losses, and maintenance requirements. With much higher rates of weight gain, the effect of the type of tissue that is being deposited becomes steadily more dominant.

The effect of malnutrition. Measurements of tissue biopsies and whole-body potassium show that there is a substantial deficit in potassium in the tissues of most malnourished children [139, 144, 146, 161]; this is brought about by slowing down of the sodium pump, which normally maintains a high potassium concentration inside the cell [162, 163]. It is thought that this change is an adaptation to conserve energy, as the sodium pump normally uses about one-third of the basal energy consumed. This adaptation probably requires about 6 to 7 weeks of undernutrition to fully develop. It is likely that the moderately malnourished child will have been underfed for at least this length of time.

The deficit is 23%, based on measurements of total body potassium, and about 11%, based on fat-free dried muscle biopsies. The tissue deficit of potassium is thus greater than that of protein.

If we assume that there is a 23% deficit in the tissue, which has to be made up in 30 days, then there is a requirement of an additional 18 mg (0.46 mmol)/kg/day (calculated as 60*0.23/30 mmol/kg/day, where there are 60 mmol/kg, a 23% deficit and repletion is to occur over 30 days) to allow for total body repletion. These values are then related to the child's energy requirements. The resulting requirements are shown in **table 10**.

The main reasons for the high content of potassium in F100 and F75 (2,400 mg/1,000 kcal) are that the tissue deficit has to be corrected more rapidly in severely malnourished children, particularly in those with kwashiorkor (7 to 14 days), and that the mortality rate appears to be lower with high intakes of potassium.

We should assume that the moderately malnourished child will have up to three loose (not watery) stools daily and that we need to repair the tissue deficit in about 30 days. **In this case, the potassium intake should be 1,600 mg/1,000 kcal. If a diet is to be formulated from local foods alone and we assume that there will be only one loose stool per day, then the requirement could be reduced to 1,400 mg/1,000 kcal.** On a local diet, the child will then need additional potassium if there are loose stools (even without clinical diarrhea).

Magnesium

In general, the need for magnesium in the food for moderately malnourished children has been largely ignored. There is a large tissue magnesium deficit in children with malnutrition, including those with moderate malnutrition. Children remain in strongly positive magnesium balance throughout recovery, and even at the time of their full recovery, after they have regained weight to reach normal weight-for-height, the magnitude of the positive balance of magnesium (avid retention in the body) is impressive and worrying [164–170]. Even current best-practice therapeutic care seems unable to fully replenish the magnesium deficit of severely or moderately malnourished patients within the time required to regain normal weight.

TABLE 9. Basal potassium requirements and effect of stool losses and a tissue deficit (mg/kg/day)

Variable	Urine/stool	Urine plus stool[a]	Urine and, stool plus Deficit[b]
Basal urine	27	—	—
Normal stool	43	70	88
1 loose stool	82	110	128
2 loose stools	90	117	135
3 loose stools	98	125	143

a. The sum of urine and stool losses

b. The sum of urine and stool losses and the required intake to replete the deficit

It is unclear whether this strongly positive balance is due to sequestration of magnesium into bone with increased bone turnover during convalescence [171], but the amount of magnesium sequestered is likely to be substantial. Magnesium may be particularly important for the stunted child who needs to grow in height. Secretion of the hormones involved in bone and calcium metabolism (parathormone and calcitonin) is markedly decreased by magnesium depletion [172, 173]. Magnesium depletion, in particular, is thought to exacerbate the osteoporosis and osteomalacia of celiac disease and Crohn's disease and may be partly responsible for the osteoporosis of malnutrition. Frequently, patients who have been treated for hypocalcemia with calcium and vitamin D are completely unresponsive because of magnesium deficiency. If magnesium is given later, the prior doses of vitamin D, to which the child was unresponsive, can now become toxic and cause potentially fatal hypercalcemia [174]; the correction of magnesium deficiency *must* accompany or precede the treatment of rickets.

A second reason for paying particular attention to magnesium is that potassium retention is absolutely dependent upon having a normal magnesium status. There is no repletion of potassium in the presence of a continuing magnesium deficit; it is likely that the delay in return of intracellular potassium concentrations to normal is related to the difficulty of replenishing magnesium. This not only applies in malnutrition; adults taking diuretics for hypertension are frequently given potassium supplements, which does not replenish their potassium deficit. If magnesium supplements are given alone (without additional potassium), the potassium status of adults taking diuretics returns to normal [175]. This is probably because magnesium is an important cofactor controlling the sodium pump [176].

There is also evidence that thiamine deficiency cannot be corrected in the presence of a magnesium

TABLE 10. Potassium requirements of moderately malnourished children (mg/1,000 kcal)[a]

Variable	No tissue deficit	Tissue deficit
Basal, normal stool	770	967
Basal, 1 loose stool	1,203	1,400
Basal, 2 loose stools	1,288	1,485
Basal, 3 loose stools	1,374	1,571

a. See **table 5** for calculations.

deficiency [177]. Whether this occurs with other nutritional deficiencies is unknown.

Given the role of magnesium in potassium homeostasis and the sodium pump, it is clear that adequate magnesium must be supplied in the diet of the wasted child. Magnesium's role in parathyroid hormone metabolism, the content of magnesium in bone, and the failure of calcium retention in the presence of a magnesium deficiency also make adequate magnesium, in an available form, a critical nutrient for the stunted child.

The starting point for the requirements is only 79 mg/1,000 kcal for normal individuals, according to the FAO. The IOM has set the requirements at 112 mg/1,000 kcal, whereas the UK DRV for younger children is 121 mg/1,000 kcal (**table 11**). This large discrepancy between the committees reflects the paucity of experimental data on magnesium requirements in normal children.

The magnesium level in F100 is 175 mg/1,000 kcal. This is probably the limiting factor in the F100 diet, particularly as bone sequestration and the needs for stunting were not taken into account during the design of F100.

Losses in normal people. There appears to be considerable variation in the availability of magnesium from the diet. This is the major factor in determining magnesium balance. Its absorption is adversely affected by fiber, phytate, and oxalic acid [9] (which are present in many foods, particularly wild foods). In addition, there may be an inhibitory effect of a high-fat diet, since the magnesium salts of the fatty acids that are released during digestion are all insoluble; this effect has not been adequately investigated [178]. It is probable that the magnesium present in breastmilk is particularly available (60% to 70%). The average availability from a mixed Western diet in adults consuming sufficient magnesium to maintain balance is about 50%. The availability falls to 35% with a high-fiber diet [9]. It is assumed that the amount of fiber in the diet will be less in therapeutic diets than in the usual diets consumed in the developing world; if this is not the case, the magnesium density should be increased by a factor of about 30%. There is an urgent need for studies of magnesium availability from typical developing-country diets.

In malnutrition, the fecal magnesium output is between 7 and 12 mg/kg/day [179, 180], with an absorption of dietary magnesium of about 30%. The normal kidney can conserve magnesium efficiently; nevertheless, in balance studies of malnourished subjects with gross magnesium deficiency, the lowest observed urinary magnesium output was 1 mg/kg/day, with most of the subjects excreting more than 2.5 mg/kg/day without supplementation. The absorption of magnesium is under physiological control and related to the intake. Normal adults with normal intestinal function consuming a low-fiber diet with high magnesium content absorb less than 25% of magnesium; absorption increases to 75% when the magnesium intake is low.

Growth. When the effects of weight gain on magnesium:energy density requirements were examined, the shape of the resulting graphs was similar to those for potassium. The graphs show that the highest magnesium:energy density requirement occurs when there is no weight gain, and that the increment in energy for weight gain is higher than the increment in magnesium that needs to be incorporated into that tissue. The type of tissue being synthesized does have an effect, but at rates of weight gain below 5 g/kg/day these effects are not as great as the uncertainties about the absorbed fraction or the other variables in the equations. These calculations do not take into account any magnesium sequestered into bone. The effects of growth and the type of soft tissue that is required to be synthesized are thus not relevant to this analysis and will not be presented.

Malnutrition. The magnesium deficit that occurs in malnutrition that needs to be made good before the individual can be expected to function normally is substantial. Biopsies of muscle show that there is often a fall from a normal magnesium level of 220 to 240 mg/kg wet weight of lean tissue to less than half this value (100 mg/kg) [167, 168]. During conventional recovery on a milk-based diet without additional magnesium, this value increased only marginally (to 135 mg/kg). On a dry weight basis there is about a 30% depletion of magnesium with respect to the protein content. The normal magnesium:potassium ratio in muscle is 0.11 mol/mol (0.07 mg/mg); the malnourished child has a ratio of 0.09 on admission, which falls to 0.08 by discharge. Thus, on the regimens used during these studies, the children's muscle did not return to normal after recovery. It would appear that there was insufficient magnesium in the diet to make up the deficit or to synthesize new tissue with an appropriate composition. It is not known what the repletion is when F100 is used (or the effect of F100 on bone health).

To make up a magnesium deficit of 100 mg (4.1 mmol)/kg of lean tissue in 30 days, a person with 70% lean tissue would have to consume an additional 2.3 mg/kg/day of magnesium to allow for soft tissue

TABLE 11. Magnesium requirements for normal children (mg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	79	63	59
IOM	—	112	78	94
UK	121	114	89	88

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; UK, United Kingdom repletion. However, as the depletion of skeletal tissue is unknown, there is a continuing strongly positive balance at recovery, and the muscle does not return to normal, it is assumed that the skeletal deficit is equivalent to the soft tissue deficit, giving a total deficit that should be made good of 4.6 mg/kg/day.

Diarrhea. There are substantial increases in magnesium losses with diarrhea. Western gastroenterologists cite magnesium deficiency as being the most frequent and troublesome deficiency in such diseases as Crohn's disease [181–183]. If we assume the minimum fecal output of magnesium as 7.3 mg (0.3 mmol)/kg/day in malnutrition, as in normal people, and we also assume that malnourished patients without magnesium supplementation, who are at the upper end of the range of magnesium outputs, have mild diarrhea, then the fecal output during the sort of diarrhea that is likely to be found in moderately malnourished children will be at least twice that found in nondiarrheal states, i.e., 14.6 mg (0.6mmol)/kg/day.

Magnesium requirements. With the use of the parameters listed in **table 12**, the requirements for magnesium under various conditions can be computed using the form of the equation given in **table 5**, substituting the values for magnesium. Fecal losses are assumed to be mainly unabsorbed magnesium, and so no adjustment has been made for the availability of magnesium lost in the stool; if there are endogenous losses, the effect of diarrhea will be increased. The resulting requirements are shown in **table 13**.

With mixed diets, it is recommended that the figure of 50% availability with some increased fecal loss be used to derive the recommendation. The requirements for increased skeletal growth also have to be considered. Thus, although there are insufficient data to make firm recommendations for the moderately malnourished, **an adequate intake should be set at 300 mg/1,000 kcal for fortified diets. Despite the lack of specific data on magnesium metabolism with F100, in view of the positive results obtained from giving F100 to malnourished children, for food-based diets it would be reasonable to reduce intake to a minimum of 200 mg/1,000 kcal for planning purposes; however, if the diet has a high fiber or phytate content or if diarrhea is anticipated, the intake should be increased.**

Discussion. The values recommended are higher than those derived for F100 (175 mg/1,000 kcal). In designing that diet, it was assumed that the magnesium would have 70% availability from a milk-based diet without fiber or phytate, and the tissue deficit was underestimated with regard to the data of Montgomery [168] but was in accord with the results published from Thailand by Caddell [164]. To assess the F100 formula, biochemical parameters, weight gain, and lean tissue growth were considered; magnesium retention, bone health, and magnesium metabolism, specifically, were not examined. In view of the persistent strongly positive balance for magnesium and the fall in the magnesium-to-potassium ratio in muscle during recovery, it would appear that magnesium may now be the limiting type II nutrient in F100. There are no data to address this problem. It would be prudent to examine magnesium metabolism in children recovering from moderate malnutrition to establish a firmer experimental basis for making recommendations on the dietary magnesium requirements for this group of children.

The effects of availability, diarrhea, and the initial deficit need to be considered in defining the magnesium requirements for the moderately malnourished rather than the normal, healthy child. About 60% of body magnesium is normally in the bones, and in malnutrition there is a very marked loss of bone [184–186]. Bone turnover increases dramatically during therapeutic feeding [171] to increase magnesium requirements over and above those needed for soft tissue repletion. Thus, for both wasted and stunted children, a level higher than that recommended for F100 would be prudent.

Other factors. There are several other factors that need to be considered in the design of the magnesium requirements.

Many magnesium salts give an unpleasant taste to foods when they are present in high concentrations. In order to improve the acceptability of any fortified foods, the salt will have to be chosen with care. "Food-grade" magnesium citrate has a neutral taste and is used in F100; it lacks the deliquescent properties of magnesium chloride and the cathartic effects of magnesium sulfate. Other salts of magnesium have been used; magnesium diglycinate appears to be better tolerated than other magnesium salts and is well absorbed in patients with poor intestinal function [187], but there

TABLE 12. Parameters used in assessing magnesium requirements in moderate malnutrition

Absorption 30% to 60%	mg	mmol
Normal muscle (unit/kg)	240	10
Normal fat (unit/kg)	24	1
Malnourished children's muscle (unit/kg)	96	4
Recovered children's muscle (unit/kg)	132	5.5
Deficit corrected over 30 days (unit/kg/day)	4.8	0.2
Urine losses (unit/kg/day)	2.4	0.1
Fecal losses (unit/kg/day)	7.2	0.3
Fecal losses, mild loose stools (unit/kg/day)	14.4	0.6
Fecal losses, diarrhea (unit/kg/day)	28.8	1.2

is limited experience with its use.

Children with malnutrition often have low or absent gastric acid [106, 188–191]. This means that inorganic salts of minerals that are insoluble or require an acid gastric environment for absorption should not be used to supplement the foods given to the moderately malnourished. Such salts include magnesium and calcium oxides and phosphates. Magnesium hydroxide was used in the studies reported from the Medical Research Council unit in Uganda [192]. Organic salts of magnesium are more available than inorganic salts [193–195]

Magnesium is a weak cation with a poor absorption. When it is given as the salt of a strong anion that is absorbed, the salt will cause a metabolic acidosis. This was shown in severely malnourished children treated with magnesium chloride, some of whom died [196]. The magnesium should always be given as the salt of a weak anion such as citrate or diglycinate.

Although magnesium is relatively nontoxic and large amounts can be administered either intravenously or by injection (it is used to treat eclampsia in large doses), this is not the case when large amounts are given orally. Epsom salts (magnesium sulfate) have been used to induce diarrhea and for the treatment of constipation. There should not be sufficient magnesium in the diet to exacerbate any diarrhea. Although this is largely a theoretical argument, because the doses used as a cathartic are high [197], the malnourished intestine may be less able to cope. This could be one reason why there has been reluctance to add sufficient magnesium to the diets of malnourished children.

TABLE 13. Potential magnesium requirements (mg/1,000 kcal)[a]

	Absorption (%)			
Condition	30	40	50	60
No tissue deficit	246	224	211	202
With tissue deficit	342	277	237	211
With some loose stools	421	356	316	290
With several loose stools	580	514	474	448

a. See **table 5** for calculations.

Phosphorus

The main phosphorus compound in vegetable diets is phytic acid (inositol hexaphosphate). This is used by plants to store phosphorus for use after germination. During plant growth, the phytate is mobilized to give the appropriate balance of type II nutrients (e.g., nitrogen:phosphorus ratio) for the formation of protoplasm. In terms of the fundamental biochemical processes, there is not a marked difference between the protoplasm of plants, animals, and humans. If the phytic acid is not absorbed, the available nitrogen:phosphorus ratio derived from the foodstuff will be unbalanced because of a limited phosphorus supply. The other type II nutrients, particularly protein, are potentially wasted from a high-phytate vegetarian diet. Such diets are generally thought to be less nutritious, because the phytic acid chelates zinc, iron, calcium, and magnesium; this is indeed a problem. However, the problem that phytic acid poses for phosphorus status is not normally a focus of attention. In the West, phosphorus intake generally exceeds requirements as a result of consumption of dairy products; people in some cultures obtain phosphorus and other minerals from chewing bones.

The situation is different with the moderately malnourished child. Nearly every malnourished child has physical signs of bony changes (swelling of the costochondral junction) [37], and x-rays show demineralization of the bones. These changes are not adequately explained by vitamin D deficiency, the classic cause of rickets. These common clinical findings in the developing world are now being described in Western children who develop phosphorus-deficiency rickets secondary to chronic ingestion of some antacids (aluminum, magnesium, and calcium salts) that make phosphorus unavailable [198, 199]. Clinical phosphate deficiency is extremely common in malnutrition [200, 201], even in malnourished adults in Western hospitals [202], and is closely related to prognosis [203]. Correction of phosphate deficiency is likely to partly account for the success of cow's milk, a particularly rich source of available phosphorus, in the treatment of malnutrition. No extraneous phosphorus is added to F100 because of the abundant, soluble, and available phosphorus in cow's milk. If other foods or ingredients low in phosphorus or high in phytate are substituted for milk, special attention needs to be paid to their phosphorus content and availability. Calcium phosphate ($Ca_3(PO_4)_2$) is often used; it is very insoluble and should not be the phosphate (or calcium) salt chosen for diets for children with malnutrition. If diets for the moderately malnourished child are being assessed for phosphorus adequacy, phytate phosphorus should be discounted from the diet. Strategies to reduce the phytate content of plants themselves and thus increase the availability of divalent cations such as iron will have to provide an alternative source of available phosphorus.

It is often thought that phosphate is mainly used for bone formation, along with calcium; this relationship with calcium is important in infants and renal patients, for whom an unbalanced calcium:phosphorus ratio in the diet can lead to clinical problems of calcium homeostasis and tetany. However, unlike calcium, phosphorus has a high concentration in soft tissues. It is the major intracellular anion, with a concentration on a molar basis of 70% to 100% that of potassium. On a total body basis, there is much more phosphorus than potassium because of the phosphorus sequestered in bone: the infant has about 5.6 g/kg and the adult 12 g/

kg [204]. The additional phosphate in adults is in bone and brain. **Table 14** shows the phosphorus content of tissues [205].

Phosphate is vital for all metabolic pathways, and nearly all active metabolites need to be phosphorylated before they can be used; phosphate compounds are the energy "transducers" of the body. A deficiency of tissue phosphate causes severe disruption to metabolism [206]; indeed, it may be that a high dietary intake of protein or carbohydrates, which require phosphate for their initial metabolism, can cause severe metabolic damage or even death in the presence of a phosphate deficiency by acute consumption of hepatic ATP [207–210].

In view of the relative unavailability of the phosphorus from phytic acid (if the food has not been either fermented or germinated), and the high prevalence of phosphate deficiency in malnourished people, it is unsafe to assume that the phosphorus contents quoted in food-composition tables (analytic values of total phosphorus) will be sufficiently available to satisfy the nutritional needs of malnourished children. The same problem has not been faced by Western committees setting recommendations, since much of the phosphate comes from a mixed diet containing dairy products. The availability of phosphates is 55% to 70% in Western adults and 65% to 90% in infants [9]. There have been few studies of phosphate availability or status among people living in developing countries consuming their habitual, restricted, vegetarian diets to guide the formulation of requirements.

There appears to be considerable variation between the committees setting the RNIs (FAO/WHO has not considered the requirements of phosphorus) (**table 15**). This is partly because the phosphorus requirements have conventionally been set with respect to maintaining a 1:1 ratio with calcium, so that when calcium requirements are judged, the phosphate requirements are derived without independent experimental data. This is not a satisfactory approach when assessing the needs of a moderately malnourished child, for whom this is one of the critical elements whose deficiency appears to be quite common. The IOM set the highest requirements for teenagers, and the United Kingdom set the highest requirements for infants.

Parameters. In malnourished children, the average minimum amount of phosphorus needed for phosphorus balance is 28 mg (0.9 mmol)/kg/day [211]. However, the IOM rejected phosphorus balance as a way of assessing the phosphorus requirement, because when the subjects are just "in balance," they have a lower than normal plasma phosphate concentration. The IOM suggests that the requirement should be set at a level that maintains a normal plasma phosphorus concentration. Phosphorus, like potassium, magnesium, zinc, and protein, is mainly intracellular (or locked in bone), and the plasma concentration not only fails to reflect intracellular or bone concentrations with fidelity but also is subject to metabolic, hormonal, and renal modulation.

For the purposes of setting the requirements for the moderately malnourished child, the minimum *average* requirement for maintenance has been augmented by 20% as an assumed standard deviation to cover most malnourished children and take account of the IOM criticism; thus, 34 mg/kg/day is set as the maintenance requirement. The tissue content is 1,860 mg (60 mmol) per kilogram of lean tissue, with about one-tenth of this in fat tissue. However, some important lipid-rich tissues, such as the brain and adrenal cortex, have high concentrations of phosphate because of their content of phospholipids.

There have been few measurements of tissue phosphate levels in malnutrition. The levels in the few samples that have been measured show a reduction of about 18% on a dry weight basis [212] (assumed to be relative to protein). On the other hand, the levels of organic phosphorus ATP, ADP, and AMP are reduced by about 50% in white blood cell samples, and creatine phosphate in muscle is also low in malnourished adults [213]. Thus, it will be assumed that the soft tissue deficit of phosphorus in moderate malnutrition is 435 mg (14 mmol)/kg (21%), which is of a similar magnitude to the deficit of potassium and magnesium. If the soft tissue deficit of phosphorus is to be made up in 30 days, there will need to be an additional retention of 14.5 mg (0.47 mmol)/day.

The availability of phosphorus is very variable in healthy children. It is low from divalent metal salts and phytic acid. Organic phosphates appear to be readily available; phospholipids are available in normal children but may be reduced in the malnourished child

TABLE 14. Phosphorus content of tissues

Tissue	Age group	Phosphorus (mg/kg)
Whole body	Infant	5,600
Whole body	Adult	12,000
Muscle	Infant	2,010
Muscle	Adult	1,820
Liver	Infant	2,560
Liver	Adult	2,670
Kidney	Adult	1,780
Spleen	Adult	2,200
Lung	Infant	1,360
Lung	Adult	1,610
Brain	Infant	1,670
Brain	Adult	3,380
Skin	Infant	1,080
Skin	Adult	430
Tissue mean	All	1,880

TABLE 15. Phosphorus RNIs (mg/1,000 kcal)

Authority	7–9 mo	10–12 mo / 7–12 mo	1–3 yr	4–6 yr
IOM	—	409	450	360
UK	634	578	285	263

IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

because of defects in bile salt metabolism [214].

For the moderately malnourished child, a phosphorus availability of 60% is assumed on the basis that the availability is similar to that of a healthy Western child. There are few data to address the values to use for these parameters; the derived values have wide confidence limits (**table 16**).

TABLE 16. Parameters used to assess phosphorus requirements

Availability	60%
Balance	34 mg/kg/day
Tissue	1.860 mg/kg
Diarrhea	68 mg/kg/day
Deficit	434 mg/kg
Replace in 30 days	14.5 mg/kg/day

Diarrhea. In ill health, phosphate plays another critical role. It is the major acid-base buffer of the body and is critical for renal excretion of acid generated in the body. Any tendency to acidosis will be ameliorated when there is a sufficiently high phosphate intake to be able to excrete sufficient dihydrogen phosphate in the urine to eliminate the hydrogen ions without compromising phosphorus status. With marginal levels of phosphorus in the diet acidosis itself can induce phosphate deficiency. When there is a relative phosphate deficiency, acidosis cannot be corrected.* Thus, conditions such as diarrhea, pneumonia, or malaria that are associated with acidosis are more likely to be fatal in the presence of a limited intake of phosphate. A corollary of this is that conditions that lead to acidosis will further deplete the body of phosphorus used to excrete the titratable acidity.

There is not only a necessary increase in the urinary excretion of phosphate in diarrhea because of the acidosis; there is also an increase in fecal phosphate loss in diarrhea, but there have been few studies on this aspect of the change in phosphate requirements that occur in ill health. To meet these additional needs, it is assumed that appropriate balance in mild diarrhea will be achieved when the daily phosphate losses are doubled. No data to address the increment in phosphate losses with diarrhea in the moderately malnourished were found. The assumption of a doubling of fecal and urinary losses might be a gross underestimate. However, **table 17** shows a balance study on malnourished children on admission and at intervals during recovery. The fecal output is about twice as great in the malnourished as in the recovered state.

Phosphorus metabolism in malnutrition is an area that requires considerable research, as the data are totally insufficient, and with the trend to use cheap ingredients, rich in phytate, to treat the moderately malnourished, the availability of phosphorus from the diet becomes a critical issue.

Growth. The specific requirements of phosphorus for growth are similar to those of potassium and magnesium, in that there is little change in the requirement per unit energy as the child's rate of weight gain increases.

Phosphorus recommended intakes. **Table 18** gives the computed requirements for phosphorus for moderately malnourished children with and without a tissue deficit and with and without diarrhea.

Discussion. As with magnesium, the calculations that have been made are for soft tissue phosphorus requirements only. No account has been taken of the needs for reossification of bone in the moderately malnourished child, for continuing skeletal growth or for accelerated height gain in the stunted child. Because of the additional requirement for bone formation, it is suggested that the phosphorus requirement for the moderately malnourished child should equal or even exceed that for the severely malnourished child. This is because the moderately malnourished child will be consuming the diet for much longer than the time normally taken to treat the severely malnourished child in order to enable reversal of stunting, during which the moderately malnourished child may have repeated episodes of acidosis and diarrhea.

It is suggested that the phytate fraction should be measured in foods used for calculation of diets for the moderately malnourished. The phytate fractions should be given in food-composition tables and completely *discounted* from any assessment of the adequacy of the phosphorus in the diet.

Therefore, it is suggested that the diet contain 900 mg (29 mmol) per 1,000 kcal of *nonphytate* phosphorus when the diet is fortified, and a minimum of 600 mg/1,000 kcal in a diet based on only locally available foods.

Many inorganic phosphorus compounds are marginally soluble and are likely to be unavailable if they are used to fortify diets or foods for the child with defective gastric acid secretion. Excess phosphate may

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* The magnesium chloride-induced acidosis only occurred when the children were on a maintenance diet similar to F75; when the growth diet, which is rich in phosphorus (with the same phosphorus density as F100), was given, the acidosis disappeared and a high urinary titratable acidity and excretion of dihydrogen phosphate occurred [196].

reduce the availability of some divalent metals. The advantage of milk is that the phosphorus is soluble and readily available. Preventing calcium phosphate from precipitating in artificially formulated diets containing the full calcium and phosphorus requirement, without using milk, presents a difficult technical problem [215] when the diet should be readily soluble.

TABLE 17. Phosphorus balance in malnourished children (mg/kg/day)

Variable	Admission	Day 10–20	Day 30–50
Intake	162.0	161.0	153.0
Urine	9.7	25.7	35.7
Feces	104.0	67.0	56.0
Balance	48.2	68.8	61.4

Source: Linder, 1963 [179].

Zinc

Zinc has been shown to be the limiting type II nutrient in many diets. Although the zinc:protein ratio is relatively constant in most foodstuffs from vegetables to meat, the availability of zinc is always less than that of protein, and therefore it is difficult to become protein deficient without being first zinc deficient [216]. Therefore, it has been suggested that, with normal diets, it is not possible to have "pure" protein deficiency. Supplementation with zinc has been shown to shorten the secretory phase of diarrhea and to have a major effect upon the recuperation of patients. Zinc is also critical for the immune response. The congenital condition acrodermatitis enteropathica, which is due to a defect in zinc absorption, is characterized by immune dysfunction and diarrhea, as well as by skin lesions and failure to grow. These same conditions characterize the problems of the malnourished child. On the other hand, high doses of zinc can interfere with copper metabolism and have other effects that are detrimental. Early studies in the United States showed that zinc was the limiting nutrient in the diets of children enrolled in the Head Start program, and zinc deficiency resulted in progressive stunting [217]. Even early types of infant formulas contained insufficient zinc for growth. Feeding recovering malnourished children with infant formula brands based upon soy protein led to clinical zinc deficiency that resulted in abnormalities of immune function, body composition, thymic regrowth, and the sodium pump [19, 29, 218, 219]. It is imperative that the diets of moderately malnourished children contain adequate amounts of available zinc.

Phytic acid is a strong chelator of zinc. This chelation is greatly exacerbated by the presence of excess calcium, and the diet should not contain excess calcium if phytate is present [220, 221]. Adding excess calcium in an effort to support bone growth can induce zinc deficiency by this mechanism, and zinc deficiency can be partly alleviated by giving a low-calcium diet [222], which presumably releases zinc locked in bone.

Because of the strong association between the dietary matrix and zinc status, FAO/WHO [7] and WHO [6], in publishing their recommendations, give three values corresponding to the different types of diet that are habitually consumed. These have an availability of 56%, 35%, and 15% of the zinc in the diet. There is little urinary excretion of zinc, and therefore urinary excretion can be quantitatively ignored.

Table 19 shows the zinc requirements recommended by the various expert committees. The Western committees have proposed a zinc intake of about 5 mg/1,000 kcal or less for children. The RNI has been considerably reduced by the IOM from the previous US recommendations [148], possibly because of domestic concerns about induced copper deficiency with high zinc intakes. Nevertheless, this large variation is mainly due to differences in assumed availability. The dietary zinc requirement published by FAO for infants consuming cereal diets typical of developing countries is over 12 mg/1,000 kcal, and the previous recommendation of the WHO/FAO/IAEA committee was 16 mg/1,000 kcal. These recommendations are for normal children consuming unknown diets. It is clear that the matrix has a dominant effect upon zinc availability and thus upon zinc dietary requirements.

Zinc losses. Fecal zinc excretion can fall to low values in zinc deficiency, and the absorbed amount of zinc needed for "maintenance" is only 0.033 mg/kg/day [6]. This seems a trivial quantity, in view of the high prevalence of zinc deficiency and the quite large amounts of zinc released into the intestine with pancreatic enzymes, many of which contain zinc.

Growth. The normal zinc concentration in muscle is about 81 mg/kg [25]. This content of zinc in soft tissue is high compared with the maintenance requirements, and thus the rate of weight gain has a dramatic effect upon the amount of zinc that needs to be present in the diet to support different rates of growth without any compromise of immune or gut function.

Conversely, during weight loss, relatively large amounts of zinc are liberated from the tissues as a result of the catabolism of muscle [223]. Anorexia is a primary and cardinal feature of persons consuming a low-zinc diet [224]. In dietary surveys, the resulting low energy intake is often interpreted as an "energy deficiency," when the prime cause is poor appetite due to an inadequate supply of available zinc [74]. With an intake less than that required for maintenance, the zinc that is released from the catabolized tissue alleviates the deficiency and relieves the anorexia somewhat, at the expense of continued gradual weight loss [225]. It is critical that there be sufficient available zinc in the diet to prevent this anorexia from occurring and to support at least normal rates of growth.

TABLE 18. Phosphorus requirements for moderately malnourished children (mg/1,000 kcal)[a]

	Rate of weight gain (g/kg/day)		
% lean tissue	2	5	10
No phosphorus deficit or diarrhea			
50	354	339	323
60	364	360	356
70	375	383	393
21% soft tissue phosphorus deficit			
50	585	534	476
60	599	560	517
70	612	589	561
21% soft tissue phosphorus deficit and loose stools			
50	918	814	698
60	936	849	749
70	954	886	804

a. See **table 5** for calculations.

Malnutrition. In severe or moderate malnutrition, muscle zinc concentration falls from about 81 to 64 mg/kg [25]. This deficit is of the same order of magnitude as that of the other intracellular minerals (21%) and is a metabolic adaptation. The zinc content of fat tissue is much less than that of muscle; the tissue deficit is thus of the order of 17 mg/kg. This tissue deficit has to be made good in about 30 days, which will require an additional retention of 0.57 mg/kg/day, a large proportion of the dietary zinc intake of normal children. There are relatively few data on the deficit in malnourished children, particularly moderately wasted or stunted children. The type of tissue being synthesized has relatively little effect upon the zinc:energy requirement within the range of 50% to 70% lean tissue synthesized, although if the proportions of lean to fat tissue change there is a significant effect. The calculations presented are for 70% lean tissue and 30% fat tissue.

Diarrhea. Not only is zinc deficiency a cause of diarrhea, but also substantial zinc is lost in the diarrheal stool. The zinc output in the feces increased threefold from 0.050 to 0.160 mg/kg/day with diarrhea [226]. However, the dominant features in deciding upon zinc requirements are the magnitude of the deficit and the rate of weight gain. Uncertainties in these assumptions far outweigh the variation due to diarrhea. For that reason, no allowance will be made for diarrhea in calculation of the zinc:energy ratio required. The resulting calculations are shown in **table 20**.

Discussion. **Table 20** shows the effect of the three different availabilities of zinc at different rates of weight gain without an initial deficit or with a deficit of either 8 g/kg or of 17 mg/kg that is to be made good in 30 days. Shown are the necessary zinc:energy densities per 1,000 kcal and the absolute zinc intake required in milligrams per kilogram per day.

Breastmilk has about 1.7 mg of zinc/1,000 kcal; this corresponds in the table to a rate of weight gain of 1 g/kg/day with a highly available source of zinc. The effects of both availability and depletion are more dramatic with zinc than with any other nutrient. The effects are of such magnitude that *it is unrealistic to attempt to replete a moderately malnourished child over short periods of time with a low-availability diet without adding large amounts of zinc.* The question arises of the utility of having sufficient amounts of the other type II nutrients in the diet to allow for rapid growth if it becomes impossible for sufficient zinc to be absorbed [75]. The RNIs for normal children living on a Western diet are completely inadequate for a wasted or stunted child receiving a cereal- or pulse-based diet. Even children consuming a strict vegetarian diet in the Netherlands grow similarly to children in the developing world [227], indicating that the infective burden or care practices are not the dominant causes of malnutrition

TABLE 19. Zinc RNIs (mg/1,000 kcal)

Authority[a]	7–9 mo	10–12 mo/ 6–12 mo	1–3 yr	4–6 yr
FAO (high)	—	3.7	2.5	2.5
FAO (moderate)	—	6.1	4.3	4.1
FAO (low)	—	12.5	10.8	9.1
IOM	—	4.5	2.9	3.6
UK	7.7	7.0	5.1	4.9
WHO (high)	—	4.9	3.5	3.1
WHO (moderate)	—	8.3	5.8	5.2
WHO (low)	—	16.5	11.5	10.4

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom; WHO, World Health Organization

a. High, moderate, and low refer to the availability of zinc from different types of diet.

in those receiving traditional weaning diets.

RUTF and F100, which are special milk-based diets for the severely malnourished, have more than 10 times the concentration of zinc found in breastmilk; with the high availability from such a diet, this amount allows repletion of the deficit and rates of weight gain of well over 10 g/kg/day. This is what is routinely found in practice; however, the rate of recovery declines markedly when phytate-containing porridges are added to the feeding regime (unpublished). The fact that even *adding* cereal-based porridges to an exclusively milk-based diet *decreases* the rate of weight gain shows not only that the zinc contained in these diets is of low availability, but also that the diets themselves interfere with the availability of nutrients such as zinc in the formula diet. If children are consuming RUTF at home with considerable amounts of high-phytate other foods, zinc may become the limiting nutrient in recovery unless the foods are consumed at different times of the day. The instructions for consuming such foods should include advice that they be consumed separately.

The amount of zinc that would need to be added to a diet to allow for catch-up at a reasonable rate and at the same time replenish the existing tissues, with a diet in which the zinc is only 15% available, is so large that a marked increase in zinc availability could potentially lead to the absorption of excessive amounts of zinc and, most certainly, to local concentrations in the intestine that would seriously interfere with copper absorption. Such sudden increases in availability could occur, for example, if the diet was fermented to reduce the phytate.

In general, the copper:zinc ratio should be approximately 1:10 on a molar basis; but if a large amount of zinc is added to achieve rapid growth in the presence of antinutrients, the appropriate absorbed copper:zinc ratio might be achieved with lower dietary ratios if the antinutrients specifically affect zinc absorption.* It is important to collect data to address this interaction in the malnourished child. Thus, it is not feasible for a child in an already depleted state to have meaningful catch-up growth on a diet with low zinc availability.

A minimum of 13 mg zinc/1,000 kcal should be given when the zinc in the diet is of moderate availability and the children are to be rehabilitated with local foods alone. If the diet is to be formulated, again in a matrix that will give moderate availability, the minimum should be increased to 20 mg/1,000 kcal.

TABLE 20. Assessment of zinc requirements with various availabilities and rates of weight gain[a]

Zinc availability[b]	Deficit (mg/kg)	RWG (g/kg/day)	Zinc requirement mg/1,000 kcal	mg/kg/day
High	0	0	0.6	0.06
High	0	2	1.9	0.19
High	0	5	3.4	0.40
High	0	10	5.2	0.74
Moderate	0	0	1.0	0.09
Moderate	0	2	3.1	0.31
Moderate	0	5	5.4	0.64
Moderate	0	10	8.3	1.18
Low	0	0	2.4	0.22
Low	0	2	7.2	0.73
Low	0	5	12.7	1.49
Low	0	10	19.3	2.75
High	8	0	6.2	0.56
High	8	2	6.9	0.70
High	8	5	7.7	0.90
High	8	10	8.7	1.24
Moderate	8	0	9.9	0.90
Moderate	8	2	11.0	1.12
Moderate	8	5	12.4	1.45
Moderate	8	10	13.9	1.99
Low	8	0	23.1	2.11
Low	8	2	25.8	2.61
Low	8	5	28.8	3.37
Low	8	10	32.5	4.64
High	17	0	11.8	1.07
High	17	2	11.9	1.21
High	17	5	12.1	1.41
High	17	10	12.2	1.75
Moderate	17	0	18.8	1.71
Moderate	17	2	19.0	1.93
Moderate	17	5	19.3	2.26
Moderate	17	10	19.6	2.80
Low	17	0	43.9	4.00
Low	17	2	44.4	4.51
Low	17	5	45.0	5.27
Low	17	10	45.7	6.53

RWG, rate of weight gain

a. See **table 5** for calculations.

b. Availability: high, 56%; moderate, 35%; low, 15%.

When very high levels of zinc are given (> 6 mg/kg/day), there is a danger of toxicity, with increased mortality [228], although in the study of Doherty et al. [228], no copper supplements were given.** The prescription of zinc as a separate supplement that is given irrespective of the appetite or physiological state of the child is different from the addition of the zinc in a fixed ratio to energy (and copper) in the food; incorporation of the zinc in the diet obviates the problem of toxicity,

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* The adverse effect of large amounts of zinc on copper absorption is mediated by induction of metallothionine in the enterocyte. If the zinc is bound to phytate or another chelating agent and does not enter the enterocyte, this interaction may not occur.

** It is also unclear whether potassium, magnesium, and the other essential trace elements were given; the children did receive a vitamin supplement.

as those who have poor appetites and are not gaining weight will consume less of the diet and hence the supplement. When children are gaining weight rapidly and are sequestering nutrients into tissue, their intakes not only of zinc but also of copper and other nutrients will increase. With F100, consumed at 100 kcal/kg/day, the intake of zinc is 2.3 mg/kg/day; when the child is gaining weight rapidly on the same diet and takes 200 kcal/kg/day, the zinc intake will be 4.6 mg/kg/day. Children very rarely consume more than this amount of food. This fundamental difference between giving a nutrient as a pharmaceutical on a body weight or age basis* and incorporating it in a diet an appropriate amount is critical when treating children with all forms of malnutrition. This is the main conceptual change in treatment with the use of diets such as F100 from the earlier practice of giving individual supplements on the basis of body weight.

Phytase

The availability of zinc, calcium, iron, phosphorus, magnesium, and even protein [229] can be considerably enhanced by adding commercially available microbial phytase to diets [2]; this has been confirmed in humans with respect to iron [230]. Addition of phytase has been successful in the nutrition of monogastric farm animals but has not yet been used for human feeding. The addition of phytase to the diet would prevent the need to reject bulk ingredients that lead to low availability of the affected nutrients from the diet. The levels of microbial phytase that have been found to lead to a linear increase in growth and nutrient utilization are up to about 2,000 units** per kilogram of feedstuff (about 500 units/1,000 kcal). It is therefore recommended that trials of the effect of enzymatic breakdown of phytic acid on the nutritional status of moderately malnourished children be conducted. Enzymatic breakdown can be effected either through externally added microbial phytase in the case of formulated foods or by fermentation or germination in the case of local food use. Even simple soaking can halve the phytic acid content [231]. It would be useful to study traditional methods of food preparation among populations living where different foodstuffs originated [59, 232].

Sodium

Sodium is the main electrolyte in the extracellular fluid. Normally there is an extraordinary capacity to conserve sodium. Adults without pathological losses can maintain sodium balance on intakes of 70 to 460 mg/day, and there are healthy populations that have a mean adult intake of about 920 mg/day. It is almost impossible to induce sodium deficiency without a pathological loss; this was achieved by McCance [233] by induction of excess sweating in volunteers. Normal intake far exceeds the minimum requirements for healthy people in nearly every country (**table 21**). The minimum maintenance amount for the malnourished child is unknown; since there is excess sodium in the body that has to be lost during recovery, there is probably little requirement in the absence of ongoing pathological losses. For the normal, healthy child, no experimental data on minimum requirements during salt restriction were found. The minimum requirement has been set at 10 mg/kg/day by extrapolation from the adult balance figures.

Taste. There is a benefit to having sodium in the diet, as it adds taste and improves the acceptability of the diet; condiments such as monosodium glutamate are on sale in most developing country markets. Although the actual requirement may be low, it is not desirable to have a very low sodium content from the point of view of acceptability. Rice diets that were formulated to treat renal failure before the development of dialysis treatment were very low in sodium, tasteless, and very difficult to eat [234].

Diarrhea. Although the capacity to conserve sodium in health is remarkable, considerable losses can occur in pathological states. The most common is infective diarrhea*** [235, 236].

It is assumed that acute episodes of watery diarrhea will be treated with oral rehydration solution (ORS). Nevertheless, there will commonly be lesser degrees of “loose stools” in the moderately malnourished.

The concentration of sodium in diarrheal stool from a malnourished child is less than in stool from a normal child producing the same volume of stool. In malnourished children without any diarrhea, the sodium output was 0.9 mg/g stool, rising to 10.1 ± 8.7 mg/g stool in malnourished children with nondehydrating diarrhea

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* When zinc tablets are given, for example, there is always the danger of an overdose, particularly if the tablets are made to taste pleasant. With a pharmaceutical approach, there is also the problem that the zinc:copper ratio may be changed, resulting in acute copper deficiency. There is also the danger of giving the tablets to a patient in an acute catabolic state when large amounts of zinc are being released from the tissues [223] and sequestered in the liver or lost from the body. Physiologically the body reduces plasma zinc during infections, since high zinc concentrations can blunt the immune response (see references in Doherty et al. [228]). These dangers are not present when the zinc is incorporated into the diet. There is no need to give higher amounts of zinc than those found in F100 (supplying 2 to 5 mg/kg/day, depending upon the intake), unless the matrix of the diet decreases zinc availability substantially, or to give additional zinc to those in an acute catabolic state (when the appetite is suppressed).

** One unit is defined as the amount of enzyme that releases 1 μmol of inorganic phosphate per minute from 5.1mmol sodium phytate at pH 5.5 and 37°C.

*** Far less sodium is lost in osmotic diarrhea, in which the main osmolytes in the stool are the substances that are malabsorbed.

TABLE 21. Sodium AIs (mg/1,000 kcal)

Nutrient	Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
Sodium	IOM	—	550	978	864
Sodium (min)	UK	503	491	529	518

AI, Adequate Intake; IOM, Institute of Medicine; UK, United Kingdom

that did not require special administration of electrolytes [157]. The output would then be up to 27 mg/kg/day (97% CI). This is thus the *minimum* requirement for sodium to cover mild diarrhea in the moderately malnourished.

The stool sodium output of normal children with infective diarrhea is higher than that of malnourished children with diarrhea. The sodium output, in mg/kg/h, amounts to about 1.43 + 1.45 multiplied by the stool volume in ml/kg/h [160].

Malnutrition. Sodium is unlike other nutrients in malnutrition, in that the total body sodium *increases* considerably instead of decreasing. This increase is probably secondary to a slowing of the sodium pump or potassium depletion, with a consequent rise in intracellular sodium [163, 237, 238]. During treatment, this sodium has to come out of the cells and be excreted; if this occurs rapidly, the patient may die from acute heart failure [239]. For this reason, sodium should be *restricted* in the diets of the moderately malnourished. When a malnourished child has a concomitant pathological loss of sodium, a difficult balance has to be struck between replacing the losses and anticipating the influx of sodium from the cells to the extracellular compartment as the child starts to recover or enters an anabolic state.

In muscle, the increase is on the order of 50% to 60% on a dry weight basis, but because the tissue is more hydrous than normal, the increase amounts to between 20% and 34% on a wet weight basis (**table 22**).

The tissue sodium concentration is about 1,380 mg/kg. Thus, during the first 30 days when a moderately malnourished child is convalescent, there is a need to *lose* the additional sodium at a rate of about 17.5 mg/kg/day. The severely malnourished child is particularly sensitive to increased sodium intake, and treatment of the malnourished child with diarrhea presents a major problem [22]. However, because of their sodium-retaining state, the diarrheal stools of malnourished children contain less sodium than the diarrheal stools of normal children, so that the stool losses of sodium are less in malnourished than in normal children. However, the diets based on the RNIs will be consumed by normal as well as by malnourished children and also by children after they have reversed their physiological abnormalities. An association between stunting and abnormal sodium homeostasis is unexplored. Nevertheless, if the normally nourished have no diarrhea and normal physiology, their sodium needs will be adequately satisfied by a low-sodium diet that is suitable for the malnourished. It is also likely that sodium will be added to the diet extraneously as condiment.

Discussion. **Table 23** shows the various sodium needs computed for normal children, those with malnutrition, and those with stool losses of 27 or 62 mg/kg/day.

If only normally nourished children were to consume a diet, the sodium recommended intakes could be set at a level that would improve organoleptic properties and give some protection against diarrhea. However, the requirements for a moderately malnourished child should be set a far lower level than those for a normal child. In areas where kwashiorkor occurs in some children, the nutritional deficiencies and physiological changes that lead to edema appear in many of the wasted children, albeit to a lesser extent than in kwashiorkor. Moderately malnourished children in these areas should not be given high-sodium diets.

The computed amount of sodium for a malnourished child with mild loose stools gaining weight at 5 g/kg/day is almost the same as the nutrient density found in breastmilk. This should be considered an adequate sodium intake for diets for the moderately malnourished.

Nevertheless, **a maximum sodium level of about 550 mg/1,000 kcal would also satisfy the normal child with mild diarrhea who is not gaining weight, as well as the malnourished child with additional losses;** it is twice the concentration found in breastmilk. Higher concentrations should not be given to children who are living in kwashiorkor areas or who are severely malnourished. It would be inappropriate to design a diet for moderate malnutrition that would be dangerous if it were consumed by the severely wasted child.

An important further disadvantage to increasing sodium intake is that it increases the renal solute load that will need to be excreted and thus increases the water requirement; this can be of major importance in desert areas.

Water requirements

Renal solute load. Water is an essential nutrient. It is required ubiquitously, and there has to be sufficient water both to excrete heat from the body and to carry excretory products in the urine. With insufficient water there is either heat exhaustion (fever) in a humid environment or hyperosmolar dehydration in a dry environment, or a mixture of both syndromes when the environment is neither very humid nor very dry.

TABLE 22. Sodium content of muscle biopsies of children with severe acute malnutrition (SAM) and normal or recovered children

Normal or recovered children (mg/kg wet wt)	SAM (mg/kg wet wt)	Increase (%)	Reference
1,408	1,693	20	Nichols, 1972 [240]
1,349	1,654	23	Vis, 1965 [241]
945	1,267	34	Metcoff, 1966 [242]
1,010	1,357	34	Frenk, 1957 [243]

TABLE 23. Sodium requirements in relation to stool losses, rate of weight gain, and nutritional status[a]

Nutritional status	Stool losses[b]	RWG (g/kg/day)	Sodium requirement (mg/1,000 kcal)
Normal	Normal	0	227
	Normal	2	221
	Normal	5	213
	Mild loose	0	530
	Mild loose	2	493
	Mild loose	5	449
	Moderate loose	0	909
	Moderate loose	2	833
	Moderate loose	5	744
Malnourished	Normal	0	0
	Normal	2	17
	Normal	5	36
	Normal	10	59
	Mild loose	0	303
	Mild loose	2	289
	Mild loose	5	272
	Mild loose	10	252
	Moderate loose	0	682
	Moderate loose	2	629
	Moderate loose	5	567
	Moderate loose	10	493
Sodium contents (mg/1,000 kcal)			
US RDA			978
UK DRV			529
Breastmilk			257
F100			434

RWG, rate of weight gain; US RDA, US Recommended Dietary Allowance; UK DRV, United Kingdom Dietary Reference Value

a. See **table 5** for calculations.

b. Stool losses: mild loose, 27 mg/kg/day; moderate loose, 62 mg/kg/day.

One of the main reasons why breastmilk is low in protein and electrolytes is to maintain as low a renal solute load as possible. The renal osmotic load from breastmilk is 145 mOsm/1,000 kcal [244].

The fixed osmolytes that need to be excreted are mainly sodium and potassium (both matched by their anions) and urea, with smaller contributions from magnesium, calcium, and phosphate. In the nongrowing individual, none of these elements are stored in the body.

If the recommendations are followed so that 26 g of protein per 1,000 kcal is consumed, of which 90% is absorbed, 135 mOsm/1,000 kcal urea will be generated. Similarly, potassium will generate 82 mOsm/1,000 kcal, sodium 48 mOsm/1,000 kcal, and magnesium 12 mOsm/1,000 kcal, including their associated anions. The magnesium will be given as an organic salt. There will be an additional load from phosphate and calcium, but this is relatively small* [245–248].

The total renal solute load that will be generated will thus be about 280 mOsm/1,000 kcal (urea + cations + anions). Additional protein or electrolytes should not be added to the diet without ensuring that there is a sufficient water intake. The suggested diet provides about twice the renal solute load provided by human breastmilk. Insensible water loss is dependent upon the temperature and the metabolic heat produced that needs to be dissipated; in general, at thermoneutrality, the insensible water loss is about 25 g/kg/day but rises exponentially as environmental temperature approaches or exceeds body temperature.

Renal concentrating ability is severely compromised in malnourished children, including those with moderate malnutrition and those who recovered on the older diets, so that the maximum that can be achieved by many children is about 400 mOsm/L, and some children cannot concentrate their urine at all [81]. If a young child is consuming 100 kcal/kg/day, contributing 28 mOsm that needs to be excreted and losing 25 g of water/kg/day through insensible loss, then the minimum water that needs to be consumed, if the urine concentration is not to go above 400 mOsm/L, is 100 mL/kg/day. If only the diet is being consumed, the energy density cannot be higher than 1 kcal/mL without the danger of hypernatremic/ hyperosmolar dehydration, and the protein and electrolyte concentrations of the diet need to be limited to levels that do not pose a threat of hypernatremic dehydration due to water deficiency [247, 249–252]. Of course if additional water is consumed with or after meals, the foods of the

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* During rapid weight gain, it is sometimes assumed that there is a substantial saving of solute load due to the osmols laid down in newly formed tissues. The saving is relatively small (0.9 mOsm/g lean tissue); this is offset to some extent by failure to generate metabolic water from oxidation of ingested fat and carbohydrate (1.07 and 0.55 mL/g, respectively) when it is deposited in tissue instead of being burned. The reason these children do not so readily develop hyperosmolar syndrome is that the increased dietary intake needed to sustain weight gain provides an increment of water over and above the fixed requirement for heat dissipation.

diet can be more energy dense. In other words, with the recommended protein and electrolyte content, if the child's diet consists only of porridge, either the energy density must not rise above 1,000 kcal/L of wet porridge or additional water must be given. The addition of oil to the diet will not alleviate the need for additional water and may aggravate the danger of water deficiency because the the energy density of the diet is thereby increased and less of the diet will be consumed to satisfy energy needs so that there will be less ingested water available for excretion of the osmolytes present in the diet.

If the temperature is above thermoneutrality (28° to 32°C), the humidity is low, the child has a fever, or the child is malnourished (and therefore the ability of the kidney to concentrate may not rise above 300 mOsm/L), then either the energy density of the porridge needs to be reduced or additional water must be consumed. These conditions of heat, low humidity, and fever are very common in most places where moderately malnourished children occur. It is dangerous to attempt to make a diet for young children excessively energy dense. In Tchad in May (with a daytime temperature of 45°C and a relative humidity of less than 15%), the water turnover of malnourished children was one-third of total body water per day [127]. The danger of having an excessively energy dense diet is particularly the case in infants 6 to 12 months of age, who cannot adequately indicate to the mother that they are thirsty rather than hungry.

The osmolarity of the diet itself is quite a different consideration from the renal solute load, since both organic (e.g., sugar) and inorganic osmolytes contribute to dietary osmolarity. There also needs to be sufficient water mixed with the diet to reduce its osmolarity to a level that can be easily absorbed by the intestine of the malnourished child and will not provoke osmotic diarrhea. One of the benefits of fat as an energy source is that there is no associated increase in the diet's osmolarity when fat is incorporated.

Type I nutrients

The considerations for type I nutrients are not the same as those for type II nutrients. Here, the maintenance or replenishment of body stores and the specific functions the nutrients play need to be considered. The requirements for these nutrients are likely to be affected particularly by the environment and the stresses to which the moderately malnourished child is exposed. These are likely to be quite different from those of a healthy Western child living in a clean, hygienic, and safe environment.

Calcium

Although not a micronutrient, calcium is nevertheless a type I nutrient, and its metabolism and retention are not dependent upon the balance of the type II nutrients (see the balance studies of Rudman et al. [75]). If we only consider soft tissue regeneration, the requirement for calcium, unlike that for phosphorus, is extremely low. The vast majority of calcium is required for bone formation, and the maintenance of bone health has not so far been considered in formulating diets for malnourished, wasted children. Nevertheless, all malnourished subjects have substantial osteoporosis [184, 185, 253]. Thus, although there is a considerable bony deficit that has to be made good, there is no substantial soft tissue requirement for calcium, and this requirement has been ignored, partly because it is assumed that the requirements will be met from milk. In malnourished children, the intracellular content of calcium is effectively zero and the extracellular level is normal. Even though the bone mineral deficit has not been quantified when the requirements for phosphorus or magnesium have been set, it is desirable that there be adequate calcium to maintain positive balance, and the phosphate:calcium ratio should be such that there is no danger of induction of hypocalcemic tetany.

The total body calcium even of normal children living in the developing world is low, and their diet is normally low in calcium [254]. Even though calcium may not be directly involved in the promotion of longitudinal growth, calcium is vital to give adequate density to the bone and prevent deformity or calcium-deficiency rickets [255, 256], particularly when the diet or supplementary food is maize based [257]. It is clear that most moderately malnourished children have been subsisting on a diet with inadequate available calcium for a long time. The diet of these children needs to contain sufficient available calcium to allow normal bone density to be restored and maintained.

The amounts of calcium recommended by the authorities are shown in **table 24**. The IOM levels are considerably below those of either the FAO/WHO or the United Kingdom for younger children and are higher for older children, with a different gradation from younger to older; the reason for this is unclear.

A phosphorus requirement of 900 mg (29 mmol)/1,000 kcal has been set (600 mg if a food-only-based approach is used). If a low calcium intake were to be recommended, then the calcium:phosphate ratio would be inappropriate.

It is appropriate that the calcium:phosphorus ratio be maintained within the range of 0.7 to 1.3 for all children over 6 months of age. **Therefore, 840 mg (21 mmol)/1,000 kcal of calcium should be included in the diet if the diet is to be fortified. This level will be impossible to reach with a food-based approach that does not include animal milk or milk products. The recommendation for the intake that should be achieved if only local foods are used is 600 mg/1,000 kcal.**

The recommendation when a fortified diet is used is higher than the FAO/WHO recommendations for normal children. Such a level would give a molar ratio of calcium to phosphorus of 0.7 mol/mol, which is adequate. It is unknown whether the food-based recommendation will supply sufficient calcium to replenish bone mineral [258]. Food constituents such as oxalate that inhibit inorganic calcium absorption do not affect the absorption of calcium from milk [259]. Although in normal adults calcium from inorganic sources is as available as calcium from milk [260], this is unlikely in children with limited gastric acid.

Nevertheless, excess inorganic calcium should not be added to the diet in an effort to overcome the inhibitory effects of phytate. Calcium phytate is a more efficient chelator of transition metals than phytic acid alone. The concentration of calcium in F100 is about 1,000 mg/1,000 kcal; on this diet, severely malnourished children have an increased bone turnover [171] and nonedematous children start to grow in length within a few days of starting the diet, even though they still have a substantial weight deficit.

Iron

Of all the nutrients that are added to rations for malnourished children, iron has received the most attention, and its nutrition has been extensively researched. The RNIs are based upon firm and extensive research data [11]. Most iron deficiency in the developing world is longstanding chronic deficiency. The diets of moderately malnourished children should not be used as a vehicle for delivery of *therapeutic* doses of iron to all moderately malnourished children to treat those in the population who are severely anemic. There are numerous programs of iron supplementation. They have not had the success of other deficiency-elimination programs. Indeed, the management of iron status is tackled more satisfactorily by giving a balanced diet with all the other nutrients necessary for efficient iron utilization and hemoglobin synthesis than by simply increasing the dose of iron. The results of one study on Saharawi stunted children are particularly illuminating; anemia responded to, and severe anemia was eliminated by, a more balanced diet [261]. Adding riboflavin to the diet had a greater effect upon ferritin levels than increasing the level of iron to the therapeutic range [262–264]; it would appear that anemia in the moderately malnourished child is usually a multimicronutrient disorder and not simple iron deficiency. There is evidence of deficiencies of many hematinics in the malnourished child: folate, cobalamin, riboflavin, pyridoxine, vitamin C, vitamin E, and copper. There are often high blood lead levels, possibly due to the low phosphate levels in the diet, leading to increased absorption. There are frequently chronic infections, malaria, and intestinal parasites. A proportion of children have hemoglobinopathies or glucose-6-phosphate dehydrogenase (G-6-PD) deficiency. Indeed, there are multiple causes of anemia in the malnourished child. There are also metabolic effects that lead to unresponsiveness of the bone marrow [265], despite high levels of erythropoietin [266].

TABLE 24. Calcium RNIs for normal children (mg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	595	523	483
IOM	—	401	489	576
UK	820	747	369	340

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

It is well known that iron deficiency is particularly common in the developing world. However, it is rarely appreciated that iron deficiency mainly affects normally grown children. In most malnourished children, including those with severe or moderate wasting or kwashiorkor, the storage levels of iron are *increased*, not decreased, even in the presence of quite severe anemia [267–276]; the increase appears to increase mortality [271, 277, 278], particularly if therapeutic iron is given [279]. There are therefore cogent reasons not to have a high iron nutrient density in diets designed for the malnourished child, particularly in areas where kwashiorkor is common. It is a mistake to assume that the anemia usually present in the malnourished child is due to simple iron deficiency alone. Treating non-iron-deficient anemia with iron or even anemia due to multiple deficiencies with iron alone, in these circumstances, may increase the mortality rate. It is for this reason that no iron is added to F100, and efforts are made to keep the ingredients as low in iron as possible. This is because F100 is sometimes used in phase 1 of treatment, when the children are acutely ill with low levels of iron-binding proteins. For diets such as RUTF that are used exclusively during phase 2 of treatment, a *modest* amount of iron is added to the formulation.

Nevertheless, iron deficiency is widespread in normally nourished and mildly malnourished children. This is partly due to the poor obstetric practice of early cord clamping, thus denying the neonate a placental transfusion during the third stage of labor [280, 281]. Iron deficiency is also common in infants who are malnourished because they have been born prematurely or had intrauterine growth retardation and have not laid down adequate iron and copper stores during gestation. Further, the older ambulant child who has intestinal parasitic infection may be iron deficient. Thus, a fine balance has to be struck so that there is sufficient iron to ensure that mild deficiency is reversed and stores are replenished without causing toxic effects in those with replete or excess storage iron.

There are a number of other reasons for keeping iron densities in the diet modest.

First, inclusion of iron, a redox-active metal, dramatically reduces the shelf-life of foods and causes rancidity and generation of free-radical products in the food.

Second, high levels of iron not only cause food to become rancid more quickly but also destroy redox-sensitive micronutrients in the food. Thus, a high iron level during cooking or prolonged storage will destroy a portion of the vitamin C [282], riboflavin, and folic acid that are critical to the health of the malnourished child population.

Third, a high intake of iron in malarious areas is associated with increased mortality [283]. Although the study of Sazawal et al. [283] did not examine food iron, it would be prudent not to add high levels of iron to a diet designed for use in a malaria-endemic area.

Fourth, there is some evidence that excess iron, as well as iron deficiency, is associated with increased infection apart from malaria [284], although most of the studies were conducted in malarious areas. Of the two conditions, iron deficiency is probably the more damaging and certainly affects a higher proportion of the anthropometrically normal population. Thus, in recommending the level of iron, a compromise has to be reached between the aim of treating those with some pre-existing iron deficiency on one hand and not either causing or exacerbating dietary vitamin deficiency (particularly scurvy) or giving excess to the malnourished or the iron replete within the population on the other hand.

Fifth, iron overload also occurs in populations that ferment food in iron cooking pots [285]. Iron overload can also occur in patients with hemoglobinopathies, which are common in malarious areas.

Sixth, iron readily forms totally insoluble complexes with selenium, particularly in anaerobic environments such as the intestine or some soils; thus, high iron intakes may precipitate selenium deficiency when selenium intake is marginal [286]. This nutrition–nutrient interaction does not seem to have been considered in the list of detrimental effects of the use of foods designed for the moderately malnourished as therapeutic vehicles.

Thus, a balance has to be struck when setting iron requirements for the moderately malnourished child.

Table 25 gives the iron requirements for normal children consuming diets with various availabilities of iron (5% to 15%). As with zinc, if the diet is such that the iron is simply not sufficiently available, there is little point in adding high levels of iron to the diet in an effort to force some into the child; the correct strategy would be to increase the availability of iron (or use a different strategy to give additional iron to those that need it). Availability has a dramatic effect upon iron requirements. It is not possible to set a single requirement. If it is assumed that the iron is 10% available, then 8.9 mg/1,000 kcal would be required.

In view of the uncertainty about whether the iron content of the diet should be increased to treat anemia or decreased to avoid deleterious effects, it is suggested that the RNIs for iron set by FAO/WHO for normal children should be applied to the moderately malnourished**.**

If the diet is to be fortified and the iron is of low availability, then 18 mg/1,000 kcal should be present; however, whenever possible, diets with low iron availability should not be formulated for treatment of the moderately malnourished. For a food-based approach and for most formulated diets, it is important that the basic ingredients be such that the iron is more available, in which case a level of 9 mg/1,000 kcal should be used.

For special groups, such as pregnant women, it is difficult to achieve a high enough iron concentration in a poor diet to satisfy their RNIs. The diet will then be potentially toxic for the malnourished child, particularly in a malarious area, and particularly if therapeutic doses of iron are given from another source so that the cumulative intake from all sources becomes excessive. The levels of iron in the diet should not be such that children who are enrolled in programs for the treatment or prevention of iron deficiency get a double dose. It would be better if an alternative strategy were used for groups with particularly high requirements, such as the use of micronutrient powders or spreads that should contain high levels of all hematinics. In formulating recommendations for iron contents in diets for general use by moderately wasted or stunted children, the needs of special groups and the use of food as a therapeutic vehicle should not be a consideration, any more than in the case of other nutrients whose deficiency is common. Thus, with respect to iron, no special provision need be made for children who are malnourished, have diarrhea, have an infection, or are convalescing from illness.

The form of iron in the food is important. Iron destroys many vitamins that are vulnerable to oxidation, including vitamin C, and it greatly decreases the shelf-life of products. For these reasons, it is strongly recommended that iron should be physically encapsulated (with material that is removed in the intestine of moderately malnourished children) or be in the form of amino acid complexes or iron-ethylenediaminetetraacetate (EDTA), which is now commercially available and has undergone successful trials. Iron-EDTA is less prone to matrix effects of the diet and, as important, is less prone to redox cycling. The additional cost of encapsulated iron or iron provided as amino acid complexes or iron-EDTA is offset by the lesser amount of iron that needs to be added, the longer shelf-life of the product, and the fact that lower amounts of the vitamins need to be added to compensate for storage losses.

The only other important redox metal is copper. The same considerations as those for iron apply to copper that is added to the diet in terms of using a stable but

TABLE 25. Iron RNIs at various levels of availability (mg/1,000 kcal)

Availability	Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
Fe (15%)	FAO	—	5.9	4.2	4.8
Fe (12%)	FAO	—	7.4	5.2	5.6
Fe (10%)	FAO	—	8.9	6.3	7.2
Fe (5%)	FAO	—	17.8	13.6	14.5
Fe (not given)	IOM	—	16.4	6.8	7.2
Fe (not given)	UK	12.2	11.1	7.0	4.6

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

available chelate and exploring microencapsulation technology.* Zinc, although a divalent transition metal, is not redox active and does not pose this problem.

Copper

Copper deficiency affects about 25% of malnourished children [287]. Clinical copper deficiency occurs particularly in the Andes [288]. Copper deficiency causes anemia, neutropenia, and osteoporosis; copper is also critical for collagen maturation. Copper deficiency is particularly associated with persistent diarrhea. Malnourished children who receive adequate copper are less likely to get an infection during recovery [289].

On the other hand, copper toxicity used to occur in some parts of India and Bangladesh where milk is fermented in brass vessels that can release sufficiently high levels of this element to produce cirrhosis of the liver [290, 291]. This is no longer a common problem, since most cooking vessels now used are aluminum, and should not be a consideration in formulating the diets. Animal milks, including human milk, are particularly low in copper (experimental animals fed exclusively on milk develop clinical copper deficiency). Physiologically, infants are born with a large store of copper in their liver (in a special fetal protein called mitochondrocuprin). Its function is to provide sufficient copper to last from birth to weaning. The breastmilk content of copper is not an appropriate guide to copper requirements. Iron and copper may be particularly low in human milk in order to control the colonization of the child's intestine by bacteria [84]. If this is so, then high copper (and iron) levels may have an adverse effect by promoting small-bowel bacterial overgrowth, a problem with all malnourished children and those with chronic diarrhea.

In contrast to iron, copper availability is adversely affected by vitamin C (it is the cupric species that is absorbed, and reduction to cuprous copper makes copper unavailable). Copper absorption is also inhibited by intakes of zinc sufficiently large to induce a mucosal block in the intestine due to the induction of metallothionine,** and large doses of zinc have led to clinical copper deficiency. In general, the molar ratio of copper to zinc in the diet should be about 1:10 to prevent zinc-induced copper deficiency*** and should not fall below 1:20.****

Copper is also a redox-active metal, and large amounts will adversely affect the shelf-life of products and potentially destroy redox-sensitive vitamins. Although the molar activity of copper in this respect is higher than that of iron, because it is present in relatively small amounts the effect is less important than the redox action of iron.

The RNIs for copper are shown in **table 26**. There is no FAO/WHO recommendation. The level set by the IOM and the United Kingdom is between 300 and 500 µg. However, with a recommended zinc intake of 20 mg/1,000 kcal, if a ratio of 1:10 is to be achieved, the intake of copper would need to be increased considerably above the recommended RNIs. Such an intake could be regarded as excessive, and certainly should not be used in areas where there is abundant adventitial copper in the diet or water.

In view of the common occurrence of persistent diarrhea in moderately malnourished children, the relatively high prevalence of copper deficiency in the malnourished, and the lack of any programs in which additional copper is likely to be added to the diet, it is proposed that the **copper density be set at 890 µg/1,000 kcal for a fortified diet and at 680 µg/1,000 kcal for a food-based approach.** This will result in a zinc:copper ratio of about 1:19, which should avoid zinc-induced copper deficiency and provide sufficient copper to allow for repletion of stores and correction of copper status in malnourished children. It is important to note that the upper limit for zinc set by the IOM has been established to prevent zinc-induced copper deficiency. It is critical that adequate copper be present in the diet to avoid this interaction.

Molybdenum in the diet, particularly in the presence of sulfur-containing amino acids or other sulfur compounds, renders copper totally unavailable by precipitation as copper thiomolybdate in the lumen of the intestine [292, 293]. Indeed, soluble thiomolybdates are now used as drugs to treat copper toxicity in

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* Indeed, chemically copper is a more potent redox agent than iron, but it is normally present in lower concentrations, so that its overall pro-oxidant effect is less.

** Metallothionine is exceptionally rich in sulfur amino acids; the relatively low levels of sulfur amino acids in malnutrition may limit metallothionine synthesis and ameliorate the interaction between zinc intake and copper absorption in these circumstances.

*** Whether the reverse interaction also occurs, as a result of metallothionine induction, is unknown.

**** This will normally occur temporarily when zinc supplements are given to children after diarrhea, when additional copper is not part of the recommendations; such treatment should not be prolonged and may be ill-advised in areas where copper deficiency is common.

animals and remove copper from the liver in humans with Wilson's disease. A high molybdenum intake has been associated with clinical copper deficiency in farm animals and humans. One of the main determinants of copper status will be the dietary molybdenum intake. In turn, the availability of molybdenum from the soil is dependent not only on the levels in the parent rocks and but also on the water level in the soil. In India, when a new hydroelectric scheme altered the water table and made molybdenum more available, widespread copper deficiency was induced in the human and animal population (Colin Mills, personal communication). Care must be taken when formulating the requirements that excess molybdenum is not present to precipitate copper deficiency in those who already have a marginal copper status, particularly as it is recommended that a diet rich in sulfur amino acids should be used. On the other hand molybdenum is an essential element, and sufficient has to be present in the diet (see Molybdenum, below).

Selenium

Selenium has been largely ignored in setting dietary levels for malnourished children; there have been fears about its relative toxicity at high levels.

It is unfortunate that the inclusion of selenium has been overlooked, since selenium deficiency has been found to be very common wherever it has been sought. The selenium content of foods is dependent upon the soil in which the plant was grown, and many areas have low levels of selenium in the soil,* so that all plant foods that are grown in these areas will be low in selenium. Although selenium is in the same class of the periodic table as sulfur, the chemistry of selenium is quite distinct from that of sulfur. The soil chemistry of selenium is critical in this process. As the soil Eh (reduction-oxidation potential) goes from an oxidizing to a reducing state, selenate is progressively reduced from selenate to selenite, to inorganic selenium, and then to selenide. Selenide and inorganic selenium are completely insoluble and are not available. Thus, wet soils where there is a high water table or a lot of organic matter (both of which reduce the Eh) are almost all selenium deficient; this applies to much of the wet tropics.

Second, there is an interaction between iron oxides in soil and selenium to bind and precipitate any selenium into insoluble complexes. Red soils are particularly likely to be selenium deficient; again, this applies to much of Africa (see National Research Council [286] for a full description of selenium soil chemistry with references).

TABLE 26. Copper RNIs μg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
IOM	—	327	332	317
UK	496	452	399	429
WHO	—	892	586	459

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

Third, like iodine, soluble selenium in the soil is readily leached to levels beyond the roots of crops, and any place that has iodine deficiency is also likely to have selenium deficiency unless the parent rock is seleniferous (e.g., parts of Venezuela). Selenium deficiency has been found in Central America, the Caribbean, Southeast Asia, West and Central Africa, and China [295–298]. It is likely that selenium deficiency is widespread in the developing world. Particularly low levels probably occur in the Congo Basin, where even maternal milk is sufficiently low in selenium to cause selenium deficiency in fully breastfed infants; the milk samples have no antioxidant power at all [299].

Selenium is important for several reasons:

First, it is central to the ability to withstand oxidative stress; the main enzymes necessary for this (glutathione peroxidases) are selenium dependent. In kwashiorkor there is evidence of an acute selenium deficiency prior to development of the disease, and the selenium status is closely related to prognosis [278, 300]. It is speculated that ensuring an adequate selenium status of the malnourished child could prevent kwashiorkor, although one study failed to prevent kwashiorkor in Malawi [301]. Malnourished children are exposed to increased oxidative stress from infections and smoke pollution; quantitative evidence for this increased stress comes from the high level of mercapturic acids (the detoxification products of radical damage) in the urine of the malnourished [128]. Therefore, an adequate selenium intake is critical for the protection of children.

Second, selenium, through a compound known as thioredoxin, is responsible for the maintenance of the redox state of cells [302]. Without adequate functioning of this compound, most of the control processes in the body are compromised [303]. This includes the leakage of sodium into cells and of potassium out of cells, as well as cardiac and renal function. Indeed, it is postulated that many of the differences between the reactions of malnourished children and well-fed Western children to infections (e.g., measles mortality) may be related to selenium status [300]. Of particular interest is the finding that selenium added *in vitro* increases thioredoxin, which can reduce the HIV virus replication rate up to 10-fold [304].

Third, selenium is responsible for the conversion of thyroid hormone (T4) to its active metabolite (T3). In

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* Particularly Keshan Province of China, where the deficiency causes Keshan disease. Low soil levels have affected farm animals and humans in many countries, including New Zealand, Finland, parts of the United Kingdom, and parts of the United States. Most of the developing world has not been surveyed. In Jamaica, the selenium concentration in free-range hen's eggs were used as a proxy for environmental selenium deficiency, which was found to be widespread [294].

areas where there is combined iodine and selenium deficiency, massive goiters occur, whereas in areas with iodine deficiency alone, the goiters are smaller [305]. Such large goiters are predictably characteristic of much of Africa. Large doses of iodine can overcome lack of the T3 hormone, even in the presence of a selenium deficiency, but where the intake of iodine is marginal, selenium status becomes critical in determining the extent of the physiological damage. Iodine deficiency is widespread; the extent to which this is due to, or exacerbated by, coexisting selenium deficiency has not been adequately investigated.

Fourth, perhaps the most important reason for paying particular attention to selenium status is its role in viral infections. It has been shown in animals and confirmed in humans that if a selenium-deficient individual acquires a viral infection (coxsackievirus was the first to be studied, as its increased pathogenicity is the cause of Keshan disease), the virus is likely to undergo a mutation in the host to produce a more virulent strain of the virus [306, 307]. This will then be passed to the next individual, who will contract a more serious form of the disease. Indeed, this is another possible reason why the measles that is found in the developing world is more likely to kill than that found in the West. This is an active area of current research. The results of these experiments provide a rationale for why flu pandemics of new virulent strains arise almost exclusively from the swine and ducks fed together in the selenium-deficient areas of China. It might be one reason why the HIV virus has mutated in Africa to give virulent strains that are of global concern. It could be such mutations that give animal virus the ability to cross the species barrier. Selenium deficiency may also be a reason why resistance to antibiotics and antimalarials arises quickly in some areas and why "new" epidemics of "exotic" diseases seem to arise spontaneously and particularly in Central and Western Africa and Southern China. The veracity of these speculations is being confirmed by current research [308–319]. Selenium deficiency causes mutations not only in viruses but also in bacteria such as *Mycobacterium tuberculosis*. The appearance of resistant strains and the progression of HIV infection are now thought to be intimately related to selenium status. However, in the past few years these new findings have been sufficiently well documented to make translation into a public health policy a priority, particularly as selenium deficiency is widespread and has many other major detrimental effects. A malnourished population, living crowded together in unhygienic environments and eating a selenium-deficient diet, is precisely the situation where such virulent strains of infective disease could arise. Even in normal British adults, selenium supplementation with 100 μg/day augmented immune function and led to more rapid removal of poliovirus (vaccine strain) from the blood and lower mutation rates of the poliovirus [320].

Fifth, in some areas of the world, such as Bangladesh, the digging of tube wells has led to an epidemic of arsenic poisoning. Selenium is the natural antagonist of arsenic; when present they are both excreted in the bile as an insoluble complex [321–327]. High doses of selenium can be used to treat arsenic poisoning and vice versa. It is possible that the high prevalence of arsenic poisoning in Bangladesh and India, where the arsenic content of the water is not enormously high, is related to coincidental selenium deficiency. Perhaps we could use the observation of arsenic poisoning as an indication that selenium deficiency is also widespread in the Indian subcontinent. Furthermore, any arsenic in the water or food will greatly exacerbate an existing selenium deficiency. In areas where this is a potential hazard, it is important to have a high selenium intake in the diet. Such considerations may underlie the lethality in some locations of arsenic-containing drugs used to treat trypanosomiasis (sleeping sickness) [328].

The grains from some parts of the United States, particularly maize, are largely selenium deficient [286]. It is perhaps important that none of the foods designed to treat moderately malnourished children have had selenium added to them. Selenium is normally omitted from the specifications and is not normally measured or assayed. It is now clear that this is a critical omission.

Table 27 gives the RNIs for selenium. The level for young children from the IOM is twice that given by FAO. The reason for this discrepancy appears to be the difficulty in assessing selenium status of a normal population or individual. The level that is present in F100 and RUTF is 55 μg/1,000 kcal. This is because selenium deficiency is so common in malnourished children and malnourished children have active infections and nutritional immunoincompetence and are living in highly stressful environments; the requirements for such nutrients are likely to be higher for those in the developing world than for those studied in safe, clean environments. It is not at all clear why such low levels were set by the FAO committee and why that committee reduced the levels previously recommended by the WHO/FAO consultation [7]. Selenium levels in human milk vary considerably, depending upon the mother's selenium status. Thus, human milk concentrations cannot be used as a guide unless we are sure that the mother's selenium status was adequate at the time of sampling. The average selenium level in human milk is about 29 μg/1,000 kcal.

The selenium contents of many of the foods and ingredients currently used to treat moderately malnourished children are low. Furthermore, there are major gaps in food-composition tables, with selenium concentrations rarely given; this is partly because of the high variability of plant selenium content, which is dependent to a large extent upon the availability and concentration of selenium in the soil in which the plants were grown.

Excess selenium is excreted in the urine. The availability of selenium is quite variable, depending upon whether it is given as inorganic or organic selenium. Selenomethionine, which is found in selenized yeast, is often used to supplement diets because of its low toxicity. However, its metabolism in the malnourished child is completely different from that of both inorganic selenium and methionine [329]. Selenomethionine may fail to treat acute selenium deficiency in animal studies. Furthermore, the same chemistry that occurs in soil can occur in the intestine. Selenium can be precipitated in an anaerobic intestine with bacterial overgrowth (highly reducing conditions); this accounts for the very high dietary selenium requirements of ruminants in comparison with monogastric animals. A high iron intake may also cause the precipitation of inorganic selenium in the intestine and induce selenium deficiency, with the attendant metabolic complications.

In view of recent research, the special vulnerability of the malnourished child, and the lack of any other public health initiatives to combat selenium deficiency, it is **recommended that the diet contain 55 µg/1,000 kcal of selenium for a fortified food approach (the same level that is contained in RUFT and F100); when a food-based approach is used, the IOM level of 30 µg/1,000 kcal can be used.**

Selenium nutrition and status should be the most active area of research in moderately malnourished child health so that these figures can be amended in the light of any new findings. The level of 55 µg/1,000 kcal present in F100 is safe and does not lead to high plasma levels of selenium.

There may be concern if these recommendations are to be followed in areas where the bedrock and plants are high in selenium (e.g., some parts of Venezuela). When we consider the nutrient contents of foods in terms of nutrient:energy density, it is clear that this problem is not of major concern. Thus, the selenium:energy ratio of the habitual foods of the population living in seleniferous areas will far exceed the densities proposed. Thus, when a fortified food containing the recommended densities of selenium is consumed in place of a local food, the total intake of selenium will fall.*

It is clear that for children living in a polluted, contaminated environment, the selenium status is more critical than it is for healthy children living in a clean, unpolluted country.

Iodine

Iodine deficiency is recognized to be widespread throughout those areas where malnourished children are commonly found. There are a number of highly successful public health measures that address this problem, particularly iodization of salt.

There is a large store of iodine in the body, so that those who are deficient have normally subsisted on a locally grown iodine-deficient diet for a long time. There should be no attempt to have sufficient iodine in the requirements to provide therapeutic levels for the chronically deficient. Sudden intake of large doses of iodine in the presence of longstanding deficiency can precipitate thyrotoxicosis. On the other hand, it is dangerous to rely on one source of iodine and have all the other foods in the diet devoid of iodine, since some within the population may not consume or receive iodized salt. In principle, we should aim at diversification of the dietary sources of essential nutrients, with no single item having such a high level that it would lead to toxicity or "double dosing" if consumed exclusively.

The whole idea of expressing nutrient requirements as densities is to enable us to design a diet that is balanced, with, if possible, several food items contributing significant amounts of each essential nutrient. Thus, iodine should be present in the diets and foods consumed by the moderately malnourished at a level that will result in a normal iodine intake when the foods are ingested to meet energy requirements. Any iodine that comes from salt will then be in addition to this normal dietary level and will help to alleviate overt iodine deficiency without the danger of excess supply. In other words, the fact that salt is being fortified with iodine is *not* a reason for omitting iodine supplementation from formulated diets for the moderately malnourished.

The recommended intake of iodine is particularly high for the infant. The FAO/WHO and IOM committees have recommended that this particular group should have a density of iodine that is more than twice that of the other groups (**table 28**). This recommendation may have been made partly in view of the recognized widespread deficiency of iodine and partly to compensate for the low levels of iodine in the breastmilk of iodine-deficient mothers.

However, in view of the widespread occurrence of iodine deficiency, the need to provide the infant with sufficient iodine from 6 months of age, and the fact that the 6- to 12-month-old infant is not likely to be fed a family meal to which distributed fortified salt has been

TABLE 27. Selenium AIs (µg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	14.9	17.8	16.9
IOM	—	29.7	19.6	21.6
UK	15.6	14.2	15.7	15.0
WHO	—	17.8	20.9	19.3

AI, Adequate Intake; FAO, Food and Agriculture Organization; IOM, Institute of Medicine; UK, United Kingdom; WHO, World Health Organization

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* The same argument applies to the copper content of fortified foods given in Bangladesh or India.

added, it is **proposed that the RNI of iodine for the moderately malnourished child should be set at 200 μg/1,000 kcal.**

For a food-based approach to treating the moderately malnourished child, the iodine level in salt should be taken into account. However, for a fortified complementary food approach, iodine should also be incorporated into the diet at the recommended nutrient density, irrespective of whether iodized salt is available in the area. The level recommended will not lead to thyrotoxicosis, even if modest amounts of iodized salt are taken along with the fortified food. F100 contains 190 μg iodine/1,000 kcal and human milk from an iodine-sufficient population about 170 μg/1,000 kcal.

Thiamine

Thiamine requirements are traditionally closely linked to energy and are calculated as nutrient densities before conversion to absolute units. This is because thiamine is the major cofactor in both pyruvate metabolism and for the hexose monophosphate shunt.

Its deficiency gives rise to wet, dry, or Shoshin beri-beri and Korsakoff–Wernicke syndrome in adults; the corresponding syndromes in children are meningoencephalitis, aphonic beri-beri, and cardiac failure. Deficiency is particularly found in poor populations that have been eating polished rice. The thiamine concentration in breastmilk rises and falls with the thiamine status of the mother, so that fully breastfed infants can die from thiamine deficiency when the mother is symptomless. Many of these deaths are misdiagnosed [330].

Deficiency is not related to anthropometric status, and fat people become thiamine deficient as readily as thin people. An anthropometric survey of the population will not warn of potential problems with thiamine status, and the anthropometric status of the breastfeeding mother is not related to the risk to her child. Deficiency is particularly likely in adults with a high alcohol intake, which may affect breastmilk being consumed by malnourished children.

Thiamine in food is unstable at neutral and alkaline pH values, and it is readily destroyed by oxidation (e.g., by iron) and heat [10]. Cooking typically leads to losses of up to 60%. It is particularly susceptible to destruction by sulfite and chlorine. Sodium hypochlorite (or metabisulfite) is commonly added as a disinfectant to water and food used to prepare meals for malnourished children; if this water is used to prepare the food without previous exposure to air, the likelihood of thiamine deficiency is increased. A high intake of sulfate, which can be reduced to sulfite by bacteria in the mouth and intestine, can also compromise thiamine status. Sulfites are added as a preservative to foods and beverages; they will destroy the thiamine. The same process occurs in contaminated food, and fermentation of rice can lead to removal of the tiny amount of thiamine present. Raw fish and some bacteria contain enzymes that destroy thiamine. Betel nut also contains a thiamine antinutrient, so that chewing betel nut as well as eating raw fish will magnify the chances of thiamine deficiency [331].

The biological half-life of thiamine is 9 to 18 days. Malnourished children who start with a poor thiamine status are likely to become overtly deficient within 2 weeks.

Thiamine is not toxic, even in very high doses.

The recommendations for thiamine are generally between 400 and 500 μg/1,000 kcal. There is little spread between the authorities, probably because they all relate thiamine requirements to energy intake in the same way (**table 29**). The FAO/WHO recommendation for normal 1- to 3-year-old children is 523 μg/1,000 kcal. F100 contains 700 μg/1,000 kcal.

Many of the moderately malnourished children treated according to these recommendations are likely to belong to rice-eating populations and will already be depleted of thiamine. It would be prudent to ensure that malnourished children consume thiamine at levels higher than those recommended for normal children.

Because losses of up to 60% may occur during preparation of meals for malnourished children, it would also be prudent to raise the levels of thiamine substantially. Thus, when a complementary or fortified food program is to be used, it is **recommended that the complementary or fortified food should contain 1,000 μg of thiamine/1,000 kcal. When a food-based approach is used, the levels should be above those for a healthy child; it is proposed that the diet contain 600 μg/1,000 kcal.**

Riboflavin

Meat, milk, and green leafy vegetables are the main dietary sources of riboflavin. These foods are not consumed commonly or sufficiently by malnourished children or by many poor people. Biochemical evidence of riboflavin deficiency is common; in Jamaica 80% of "control" children failed to meet the international standards for riboflavin sufficiency [332], and similar results have been found in most developing countries [264]. In India, Indonesia, and elsewhere, riboflavin deficiency is a major cause of mild anemia, and hemoglobin levels do not return to normal in these

TABLE 28. Iodine RNIs (μg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	201	78	89
IOM	—	193	88	65
UK	94	85	73	75
WHO	—	74	94	72

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom; WHO, World Health Organization populations with the administration of iron unless riboflavin, which is needed for iron utilization, is also administered. Riboflavin deficiency is also a cause of poor intestinal absorption [333, 334].

Unfortunately, the clinical signs of severe riboflavin deficiency are not pathognomonic. Riboflavin is essential to the metabolism of carbohydrates, amino acids, and lipids. It is also the critical cofactor in glutathione reductase, an enzyme that is essential for protection against oxidative stress. Any population that is exposed to excess oxidative stress needs additional riboflavin. Epidemic severe riboflavin deficiency has occurred in Bhutanese malnourished children in Nepal, where large numbers of subjects developed classic overt riboflavin deficiency [335, 336].

Riboflavin is heat stable, and little is lost during cooking. However, it is very susceptible to destruction by exposure to light or any other free-radical process. Thus, not only is riboflavin important in those exposed to oxidative stress, but also oxidation either in the food or in the body will greatly increase the loss of riboflavin. As with vitamin C, destruction during cooking may be partly due to the high iron content in the diets, such as CSB, used as relief rations and for treatment of moderate malnutrition**.**

There is remarkable consistency across age groups, physiological states, and different committees in the recommendations for riboflavin (**table 30**), with levels around 600 μg/1,000 kcal for normal people living in uncontaminated environments.

Normal subjects who were fed 550 μg of riboflavin/day (approximately 250 μg/1,000 kcal) for 4 months developed overt clinical signs of deficiency [337, 338]. This early work on human deficiency shows that the margin between adequacy and clinical deficiency is quite narrow. The level giving clinical deficiency approaches the IOM value for 4- to 8-year-old children when allowance is made for a 10% standard deviation. It is possible that with more stringent ways of assessing the riboflavin intake required to remain healthy, these figures will be increased. Most committees are reluctant to raise the RNIs to higher levels because so few apparently healthy individuals would then meet the requirements; however, whenever investigations have been carried out, a high prevalence of biochemical deficiency has been found in apparently healthy people. Furthermore, the role of riboflavin as part of the antioxidant repertoire has not been adequately assessed, and as more sensitive ways of assessing status are developed, it is anticipated that the RNIs will be increased.

TABLE 29. Thiamine (vitamin B_1) RNIs (μg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	446	523	483
IOM	—	446	489	432
UK	312	427	523	525

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake

TABLE 30. Riboflavin (vitamin B_2) RNIs (μg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	595	523	483
IOM	—	595	489	432
UK	625	569	628	600

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

Most of the present products used to treat the moderately malnourished have well in excess of each of the committee's requirements for riboflavin (800 to 3,000 μg/1,000 kcal). Because of riboflavin's critical role in oxidative stress, the riboflavin content of RUTF/F100 is 2000 μg/1,000 kcal. Other nutrients that are important for oxidative protection and whose half-lives have been measured show a dramatic increase in turnover with even mild oxidative stress, the most compelling example being the effect of smoking on vitamin C turnover (see Vitamin C, below).

The moderately malnourished are exposed to considerable environmental and infective oxidative stress at least as great as in the United States, and many will be recuperating from illness. Furthermore, the margin of safety between the levels that cause overt deficiency and the estimated average requirement is narrower for riboflavin than for most other micronutrients.

It is recommended that the level of riboflavin be set at 1,800 μg/1,000 kcal for the moderately malnourished child when a fortified-food approach is used (riboflavin is nontoxic even in very high doses and is relatively inexpensive). When a food-based approach is used for the moderately malnourished child, the RNI for healthy children is inadequate, and a level of 800 μg/1,000 kcal could be used.

Niacin

Deficiency of niacin is particularly associated with a maize-based diet. Recurrent epidemics of pellagra have occurred in Mozambique, Angola, and elsewhere in the recent past [339–344]. Niacin nutrition is likely to be, at best, marginal over much of Africa, where maize is the staple food and the population do not use the alkalinizing culinary techniques of Central America. It should be emphasized that pellagra is not due simply to a lack of niacin in the diet. Rather, it is a multinutrient deficiency syndrome in which insufficient conversion of tryptophan (protein) to niacin occurs and there is not sufficient preformed niacin in the diet to compensate for this inadequacy. The conversion is sensitive to tryptophan, pyridoxine, riboflavin, iron, and zinc status, so that a person with pellagra is likely to be marginal or deficient in several nutrients. Indeed, there is still uncertainty about the exact dietary deficiencies that lead to some outbreaks of pellagra [345]. Although about 60 mg of tryptophan will give rise to 1 mg of niacin, there is a large interindividual variation in the efficiency of this conversion, the hormonal, genetic, and biochemical bases of which are incompletely understood. Although pellagra can be treated with therapeutic doses of niacin, this conversion is vital to maintain niacin status with normal dietary intakes; few individuals could survive on the levels of preformed niacin found in foods. Thus, individuals with a perfectly adequate niacin intake, but a deficiency of tryptophan, develop pellagra.* For this reason, there is uncertainty about each of the factors affecting niacin status of individuals: the total amount of niacin required for normal metabolism: the commonly used conversion factor of 60 mg tryptophan generating 1 mg of niacin: and, the extent of interindividual variation (particularly in females and in pregnancy); the experimental basis is not sufficiently firm to set population requirements confidently. How these values are affected by malnutrition appears to be unexplored. Milk, which is low in preformed niacin, quickly relieves the symptoms of pellagra, presumably because of its tryptophan content.

The typical skin lesions of pellagra are caused by lack of antioxidant protection against ultraviolet light energy (a free-radical initiator); this is thought to be because of inability to regenerate enough of the niacin-derived compound NADPH. Apart from the other nutrients involved in the conversion of tryptophan to niacin, riboflavin and thiamine are also critical in the regeneration of NADPH; furthermore, most patients with pellagra have insufficient compensatory skin protection from the other antioxidants, so that the appearance of the skin lesions in pellagra is more complex than simply niacin and tryptophan metabolic defects. The importance of this is that there can be actual niacin deficiency, affecting many other bodily functions, without the typical skin lesions if the skin antioxidant defenses are otherwise adequate or sunlight exposure is minimal. Typically, the skin that is not directly traumatized by the sun looks and feels entirely normal.

The nutrients implicated in pellagra are type I nutrients, with the exception of zinc and tryptophan, so that an anthropometric survey will not inform us of the pre-existing status of the children in the area of the malnourished. Indeed, when they are switched to a pellagragenic diet, it has been observed that fat people tend to show symptoms before thin people. Within a family, adults, particularly women,** tend to develop the skin lesions. Other family members who eat the same diet and have similar niacin:energy requirements are not so diagnosed; indeed, the lesions that constitute the case definition of pellagra are said not to occur in younger children. Thus, children and others may be susceptible to the other features of niacin deficiency (diarrhea and a cerebral dysfunction similar to dementia) without showing the classical skin lesions that are central to the case definition and clinical recognition. A further complication is that the skin lesions are similar to those of kwashiorkor (indeed, kwashiorkor was at one time termed "infantile pellagra" [349]).

It is unknown how frequently diarrhea among children in areas and families prone to pellagra is due to niacin deficiency rather than infection, but the possibility that the symptoms of deficiency are quite different in children and that at least some of the cases of diarrhea are misdiagnosed needs to be entertained. If this is so, then the prevalence of niacin deficiency and the public health measures that should be instituted will be more important than currently assumed.

Niacin is stable during storage and with normal methods of food preparation (moist heat). It is present in many foods covalently bound to small peptides and carbohydrates and is not released by digestion, so that the availability is normally only about 30%. Alkaline heat hydrolysis of the covalently bound niacin improves availability.

The RNIs for niacin are consistent across age and physiological states, with between 6 and 7 mg/1,000 kcal being required by normal, healthy children (**table 31**).

Higher amounts are added to foods used for rehabilitating the moderately malnourished. Because maize is frequently the staple food of malnourished children and maize itself is often a basic ingredient in many diets used for the moderately malnourished (e.g., corn-soy blend and Unimix), niacin levels for these children should be substantially above the requirements for normal children. F100 has 10 mg of niacin/1,000 kcal but also contains high-quality milk as its base, with adequate levels of tryptophan.

Tryptophan levels are important in consideration of the levels of niacin to have in the diet. The requirements for normal children were set by the IOM and FAO/WHO on the basis that normal, healthy children would receive high-quality protein and milk in their diets; this is often not the case with the diets consumed by moderately malnourished children.

It is therefore recommended that if a fortified-food approach is used, there should be a threefold

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* This occurs in Hartnup disease (from renal loss of amino acids) and in persons with carcinoid tumors (from consumption of tryptophan to synthesize serotonin, the product of this tumor), both of which result in increased tryptophan loss from the body but have no influence on preformed niacin metabolism.

** Female sex hormones reduce the conversion of tryptophan to niacin [346–348]. It is likely that the conversion factor of 60 mg tryptophan:1 mg niacin is less efficient for postpubertal females and is particularly compromised in pregnancy.

increase in niacin for the moderately malnourished child to 18 mg/1,000 kcal. For a food-based approach, the FAO/WHO level for 4- to 6-year-old children should be increased by about 30% to 8.5 mg/1,000 kcal. This level is approximately the level set by the UK DRV committee and should allow for the replenishment of niacin stores.

TABLE 31. Niacin RNIs (μg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	5,947	6,276	6,439
IOM	—	5,947	5,867	5,763
UK	6,245	7,112	8,368	8,252

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

Pyridoxine

Pyridoxine is mainly used for the metabolism of amino acids. There have not been reports of clinical deficiency in malnourished children. This may be because the clinical symptoms of pyridoxine deficiency can all be ascribed to other causes (seborrheic dermatitis, anemia, fatty liver, mouth lesions, neuropathy, seizures, and mental changes), and there are no pathognomonic features. On the other hand, each of these clinical features is commonly encountered in pediatric practice in Africa and elsewhere in the developing world. Thus, the most likely reason for a lack of clinical recognition is that deficiency has not been sought. It is of great interest that one study of breastmilk pyridoxine in Nepalese women showed it to be about 10% of that in American women [350, 351]. Thus, there may be widespread unrecognized compromised pyridoxine status.

Animal sources of pyridoxine are highly available, but in plants a variable proportion is in the form of glycosides (20% in rice, 28% in wheat, and 15% to 57% in beans). These forms are not as biologically available as animal sources of pyridoxine (there is controversy about the precise availability in humans, but it may be low). However, the presence of these glycosides in food or in the intestine even reduces the availability of free pyridoxine from other sources, possibly by blocking transport processes. For example, the pyridoxine of wheat bran is largely unavailable in the form of glycosides; adding wheat bran to food reduces the absorption of all the pyridoxine in the diet. These are the probable reasons for the low levels found in Nepal and elsewhere where whole grain is used as the basis of the diet. It is possible that all populations subsisting on whole cereals and beans have a poor pyridoxine status. The biological half-life of the pyridoxine pool is about 25 days. There are no convenient field tests of pyridoxine status, so that with the lack of clinical signs, its deficiency is normally not recognized.

It is important that pyridoxine status may affect the behavior of both the mother and the infant; a low pyridoxine status is related to poor mother–infant interaction [352]. Abnormal behavior is frequently seen in both malnourished infants and their mothers. If this is partly due to deficiency of a simple vitamin, supplementation with the vitamin would make a substantial difference to the success of programs aimed at improving the care of infants and children.

Pyridoxine in food is stable under acid conditions but breaks down when in a neutral or alkaline matrix (the conditions that make niacin available). The losses in cooking vary from 0% to about 40%. However, pyridoxine hydrochloride, the normal food additive, is remarkably stable and little loss occurs.

Pyridoxine requirements are fairly uniform across committees and age ranges as compared with those of other nutrients. The highest requirements for normal people are those from FAO/WHO (**table 32**).

The levels of pyroxidine that have been included in foods for malnourished children are much higher than these values. This is appropriate for several reasons: there is likely to be a pre-existing deficiency in children whose intakes have been largely from whole-grain cereals (nearly all the developing world) and pulses; breastmilk pyridoxine is low in the beneficiary populations wherever it has been measured; the availability of pyroxidine from most diets will be lower than that assumed by the committees making recommendations for developed countries; many cases that do occur will not be correctly diagnosed, so that deficiency will be unrecognized; the body stores of pyridoxine are depleted in the moderately malnourished child and they should be made good; the pyridoxine status may become precarious if the child will subsequently be consuming a diet based upon maize, beans, and oil; and the matrix of foods used to supplement the diets of the malnourished frequently adversely affects pyridoxine bioavailability. These are not considerations pertinent to the committees that set the RNIs for healthy Western children.

Thus, similarly to the other water-soluble vitamins, it would be prudent to substantially increase the pyridoxine intake of the moderately malnourished child.

It is recommended that the pyridoxine requirement be set at 1,800 μg (1.8 mg)/1,000 kcal for a fortified-food approach. When mixed diets are being designed from local foods, a level of 800 μg/1,000 kcal should be adequate, unless the children are receiving milled whole cereals, in which case the level should be increased to 1,000 μg/1,000 kcal.

Cobalamin (vitamin B_{12})

Vitamin B_{12} does not occur in plants. The populations where moderate malnutrition is common are almost entirely vegetarian by necessity. Surprisingly, the circulating levels of vitamin B_{12} in severely malnourished children are not low [297, 353–358]. This may be because concomitant liver injury releases cobalamin into the circulation [358, 359]. The levels have not been examined with modern methods, and liver stores have not been measured. Ruminants get their vitamin B_{12} from bacterial and protozoal synthesis in the rumen. Synthesis of vitamin B_{12} may be one beneficial effect of small-bowel bacterial overgrowth when the dietary intake is very low [360, 361], but intestinal bacteria also convert dietary vitamin B_{12} into nutritionally inert metabolites [362, 363], so that the net effect of small-bowel bacterial overgrowth is normally detrimental.

There are normally large stores of vitamin B_{12} in the liver, so that clinical deficiency can take many years of depletion to develop in adults. However, the finding that the breastmilk levels in Guatemala were low is of concern [364]. As with pyridoxine deficiency, there seem to be behavioral changes in the mother–child relationship with vitamin B_{12} deficiency [365]. Young children of vitamin B_{12}–deficient mothers often have depleted liver stores and are more anemic than those of normal mothers. The diets that are usually given to malnourished children are almost devoid of vitamin B_{12}. Because of its long half-life, many consider that vitamin B_{12} status will remain stable over the course of treatment of moderate malnutrition. This is to ignore the likelihood of a pre-existing marginal vitamin B_{12} status in a child with a vegetarian mother consuming an exclusively cereal-based diet. It would be prudent during treatment of moderate malnutrition to ensure that adequate liver stores are established to maintain the child until family food containing animal products is consumed.

The absorption of vitamin B_{12} is particularly complicated; it requires a complexing protein secreted by the stomach; the complex is absorbed in the terminal ileum. Any atrophy of the stomach or disease of the ileum compromises vitamin B_{12} absorption, so that patients with malabsorption frequently present with vitamin B_{12} deficiency [366]. Malabsorption causes vitamin B_{12} deficiency much more quickly than does dietary deficiency, because the enterohepatic circulation of vitamin B_{12} is disrupted. For these reasons, it is necessary to have adequate vitamin B_{12} in the recommendations for moderately malnourished children, despite the long half-life of vitamin B_{12} and the large hepatic store in a healthy Western child.

Persons who are marginal in vitamin B_{12} and are given large folic acid supplements will first present with severe and irreversible neurological disease rather than the normal presentation of anemia [367–369], although the evidence comes mainly from the older literature; the levels of folate intake recommended have not been shown to precipitate B_{12}-deficient neurological disease [370], although it remains a theoretical possibility [371]. In the presence of vitamin B_{12} deficiency, folate is not recycled in the body, as it becomes “trapped” in its methyl form so that the person becomes dependent upon the daily intake of “fresh” folate. Folic acid is frequently given to children (and, along with iron, to pregnant women) in largely vegetarian populations without attention to their vitamin B_{12} status.These people could develop irreversible spinal cord damage or dementia. For populations consuming the typical developing-country diet, all programs that supplement with folic acid should also include vitamin B_{12}.

TABLE 32. Pyridoxine (vitamin B_6) RNIs (μg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	595	523	483
IOM	—	446	489	432
UK	468	569	732	675

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

The RNIs for vitamin B_{12} are given in **table 33**.

Vitamin B_{12} is not toxic, even at high levels, and is stable in foods.

It would be wise to take the opportunity of giving moderately malnourished children under treatment sufficient vitamin B_{12} to replete their hepatic stores. Vitamin B_{12} is the only essential nutrient that is known to be completely absent from the exclusively plant-based diet of most malnourished children.

As most moderately malnourished children will be under treatment for a relatively short time, it is recommended that 2.6 μg/1,000 kcal be set as the recommended intake of vitamin B_{12} when a fortified or complementary food program is designed. For a food-based approach, a level of 1.0 μg/1,000 kcal, as recommended by FAO/WHO for the older child, should be used.

Folic acid

It has long been recognized that folate deficiency is common in the developing world. About 20% of children in Jamaica and Kenya are folate deficient, and similar results have been published from many countries [297, 356, 372–374].

Folic acid (the monoglutamate), which is the form added to food, is at least 85% available. Food folate is normally only 30% to 80% as efficiently absorbed as folic acid. Food folate occurs mainly with a long polyglutamate side chain that needs to be hydrolyzed by a zinc-dependent intestinal enzyme, conjugase, before absorption. There are inhibitors of this conjugase in many plant foods; for example, human conjugase is inhibited by 16% to 35% by beans and by 28% by maize. Banana, tomato, and orange juice are more potent inhibitors [375, 376]; this may be of relevance in plantain- or banana-eating cultures such as Uganda. Conjugase is defective in persons with a deficient zinc intake. Although the availability of food folate from Western diets is about 50%, it is likely to be considerably lower from maize- or plantain-based diets. Inhibition of conjugase by specific foods is not often considered when antinutritional factors in foods are examined.

Folate is readily oxidized in food in the presence of iron, heat, or light. Cooking oxidizes tetrahydrofolate to the dihydrofolate, so that about half of the folate in cooked food is in the form of 5'methyl-5,6-FH2. In the acid conditions of the stomach, some oxidized folate may isomerize to a form (5'methyl-5,8-FH2) that is totally unavailable. The utilization of folate is dependent upon having an adequate status of iron, zinc, and vitamin C, nutrients that are frequently deficient in poor populations.

The recent FAO/WHO and IOM committees have established folate requirements that are substantially above those of previous committees (**table 34**). This is largely because of the recognition that homocysteine level in plasma is a more sensitive test of the adequacy of folate status than those used previously. F100 and RUTF have folate concentrations of 350 µg/1,000 kcal.

Because of the high level of deficiency of folate in malnourished children, the poor availability of natural folate from many diets, and the effect of concomitant deficiencies on folate status, the diet given to a malnourished child should contain substantially more folate than that of a healthy Western child, provided that there is also vitamin B_{12} fortification.

For a fortified-food approach, a folate level of 350 µg/1,000 kcal (the same level as that in RUTF and F100) is recommended. When a food-based approach is used, the folate level in the diet should be 220 µg/1,000 kcal; this is 30% above the level for a healthy child.

Ascorbic acid (vitamin C)

Moderately malnourished children have had few fresh fruits or green vegetables in their diets for considerable periods, so that their vitamin C status is usually precarious. The bone changes seen in scurvy (scorbutic rosary) are common in malnourished children. These bone changes do not occur rapidly, so that the severely malnourished child will have been consuming a vitamin C–deficient diet during the development of the condition, certainly during the period when the child was moderately malnourished. It is likely that the blue sclerae seen frequently in many parts of Africa are due to abnormalities of collagen formation that could be caused by chronic vitamin C (or copper) deficiency.

TABLE 33. Cobalamin (vitamin B_{12}) RNIs (ng/1,000 kcal)[a]

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	743	941	966
IOM	—	743	880	864
UK	625	569	523	600

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

[a] It is currently thought that the vitamin B_{12} RNIs may have to be revised upwards (L.H. Allen, personal communication).

TABLE 34. Folate RNIs (µg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	119	167	161
IOM	—	119	147	144
UK	78	71	73	75

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

In northern Kenya, epidemic scurvy occurs annually in the refugee camps. The problem is such that a special report was commissioned from the IOM to address this issue [282]. The IOM advised that the cooking losses were so substantial that food fortification was unlikely to help; however, the foods tested contained high levels of iron added in an effort to combat anemia.

Thus, in setting vitamin C requirements for the moderately malnourished, it is important to examine the availability and stability of vitamin C in the foods. The families of subsistence farmers who harvest once or twice per year and store their grain for prolonged periods are particularly at risk, since food vitamin C is quickly destroyed as food is dried and stored. Similarly, pastoralist communities rarely have access to fruits and green vegetables.*

Since ascorbic acid can overcome the antagonistic effect of polyphenols, phytate, and calcium phosphate on iron absorption, reducing the iron level and increasing the ascorbate level of supplementary foods may even have a beneficial effect on iron nutrition. The relatively high level of vitamin C in a spread given to Saharawi children may be partly responsible for its success in reversal of anemia, despite the relatively modest levels of iron in their diet [261].

Ascorbate is very vulnerable to oxidation (the dehydroascorbic acid is oxidized with irreversible opening of the lactone ring). It normally decreases rapidly in stored foods; oxidation is enhanced by exposure to air, traces of iron, or heat and is worse in a neutral or alkaline matrix. There are also ascorbate oxidases in many plant tissues. Rapid heating to levels that destroy these oxidases can help preserve vitamin C in diets.

Vitamin C is the major antioxidant of the aqueous body; it also regenerates oxidized vitamin E. However, in the presence of free iron it becomes a pro-oxidant through its reductive activity [377, 378].

The recent IOM committee report has considerably increased the RNI of vitamin C for the young child; for older children, the levels are lower than those set by other committees (**table 35**). It is unclear why these dramatic differences should be recommended.

Malnourished children are exposed to greatly increased oxidative stress as compared with healthy Western children. For example, in setting the RNIs for

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* Milk, particularly camel's milk, is a source of vitamin C.

vitamin C, the IOM recommends a much higher value for smokers than for nonsmokers. Similarly, patients with "oxidative" diseases such as rheumatoid arthritis have chronically low vitamin C levels and greatly increased rates of disappearance of vitamin C after a test dose is given [379].

The highest recommended value of vitamin C from the IOM committee is 74 mg/1,000 kcal for the older infant.

Vitamin C is one of the more expensive ingredients in the mineral and vitamin mixes used to make fortified foods. Nevertheless, it is clear that the vitamin C status of most moderately malnourished children is severely compromised and that they live under polluted, unhygienic conditions. It is important not to have a high level of iron in any fortified food if vitamin C deficiency and pro-oxidant effects are to be avoided [378].

It is recommended that a vitamin C level of 100 mg/1,000 kcal be used for fortified foods. For a food-based approach, the IOM level of 75 mg/1,000 kcal is appropriate.

TABLE 35. Ascorbic acid (vitamin C) RNIs (mg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	44.6	31.4	24.1
IOM	—	74.3	14.7	18.0
UK	39.0	35.6	31.4	22.5

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

Vitamin E

Vitamin E is the principal fat-soluble antioxidant of the body. In particular, it protects cell membranes and the brain. It also prevents the essential fatty acids from being oxidized. Whenever vitamin E has been measured in malnourished subjects, it has been found to be deficient [355, 380–389]; no article could be found in which vitamin E levels were normal in malnourished subjects. Vitamin E occurs with fat in the diet. In contrast to vitamin A, there is no provitamin that can generate vitamin E, so that a low-fat diet will nearly always be deficient in vitamin E. Thus, when there is vitamin A deficiency there is almost certainly concomitant vitamin E deficiency. Many seed oils are good sources of vitamin E. The typical diet of most moderately malnourished children is characterized by low levels of fat, and tropical oils have lower levels of vitamin E than temperate seed oils (e.g., coconut oil and red palm oil are not good sources of vitamin E). Many commercial oils are fortified with synthetic antioxidants (butylated hydroxytoluene [BHT] and butylated hydroxyanisole [BHA]) because vitamin E is usually lost during refining. They do not contain sufficient vitamin E, and the added antioxidants, although they prevent the oil from becoming rancid, have no biological function; they cannot replace or minimize the requirement for vitamin E in the body. The requirement for vitamin E is greatly increased by any oxidative stress and by a high intake of polyunsaturated fatty acids, which increase both vitamin E turnover and requirements. Vitamin E is critical for the proper functioning of the immune system as well as for maintenance of membrane integrity.

The differences between the recommendations of the different committees are illustrated in **table 36**. The levels of vitamin E set recently by FAO/WHO are substantially higher than those of any other committee.* Some committees set their values for vitamin E entirely in relation to the amount of polyunsaturated fatty acid recommended for the diet. This would not be appropriate for people living in the developing world.

However, higher levels of vitamin E are suggested for infants, because brain hemorrhage, hemolytic anemia, and edema have been described in Western premature infants on a low vitamin E diet [390]. Apart from these catastrophic effects, lesser levels of vitamin E deficiency, like lesser levels of the other antioxidants, are not associated with any characteristic signs or symptoms, apart perhaps from the host response to infections such as measles. Most breastmilk samples measured have a relatively low vitamin E content, which can be greatly increased by dietary supplementation [391]. Breastmilk vitamin E is lower in women exposed to the oxidant stress of smoking [392], presumably as a result of increased metabolic destruction under such conditions. Women in countries such as Bangladesh [393] have low levels of vitamin E in their breastmilk.

The malnourished child is particularly prone to oxidant stress and has low levels of many of the antioxidants [278, 300, 394–397], including vitamin E.

There is an important interaction between vitamin E and selenium. Selenium is a critical nutrient that has been neglected but that is involved in infection, virulence of organisms, emergence of new organisms, immune function, and protection from oxidative stress. It is equally critical that there be sufficient vitamin E to augment selenium in these functions. According to Beck, "deficiencies in either Se or vitamin E results in specific viral mutations, changing relatively benign viruses into virulent ones" [318]. In view of this, it is critical that sufficient vitamin E be given to those living under unhygienic conditions and other

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* It is now thought that the RNI for vitamin E may have been set at too high a level for residents of the United States (L. H. Lindsey, personal communication). However, it would be quite unacceptable to recommend that the malnourished, who are ubiquitously deficient in vitamin E, be given vitamin E at a lower level than that proposed officially for normal, healthy children. No reports could be found that give data on the physiological requirements for vitamin E, vitamin E turnover, or biomarkers of vitamin E status in malnourished children or those living in situations of infective or environmental stress, apart from simple plasma vitamin E levels.

environmental stresses.

The highest recommended intake of vitamin E is set at 8.9 mg/1,000 kcal. The level in F100 and RUTF is 22 mg/1,000 kcal, considerably above any of the committees' recommendations. This level was set deliberately for the malnourished in view of their infective burden, exposure to oxidative stress, and pre-existing vitamin E deficiency.

In view of the low level of fat in the habitual and home diets of malnourished children and their heavy exposure to pollutants and infection, the levels that are recommended for healthy Western children are quite inadequate for these children.

Thus, for a fortified or complementary food approach, it would be appropriate to have the same level of vitamin E as in RUTF (22 mg/1,000 kcal). This level cannot be reached by a food-based approach. For a food-based approach, an increase of 30% over the requirement for a healthy child living in a hygienic environment would be appropriate; this would result in a requirement of 11.5 mg/1,000 kcal.

Retinol (vitamin A)

Retinol deficiency is widespread in those parts of the world where moderate malnutrition is common. Its deficiency leads not only to blindness but also to dysfunction of mucosal surfaces and the immune system. Vitamin A metabolites interact with the genome to control the sequence of expression of various genes. Retinol is therefore of fundamental importance to the whole of the body and not only to eyesight, although eye signs and symptoms are used clinically to diagnose vitamin A deficiency. Vitamin A supplementation has been shown in several trials to have a dramatic effect upon rates of infectious disease and mortality under stable conditions [398–401]. Mortality from such conditions as measles is reduced substantially if the vitamin A status of the host is normal. In much of the developing world, distribution of vitamin A capsules with vaccination is routine practice. These programs are successful. However, concern has arisen about the teratogenic effects of vitamin A in high doses and the more recent demonstration that high doses of vitamin A are associated with increased mortality and increased respiratory tract infection in children with severe clinical malnutrition [402, 403].

The highest RNIs are for young children (**table 37**) and lactating mothers. It is quite unclear why the IOM recommendations for infants and young children differ so markedly from each other.

TABLE 36. Vitamin E RNIs (mg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	8.92	5.87	5.04
IOM	—	4.01	5.23	4.02

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake

TABLE 37. Vitamin A RNIs (μg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	595	418	362
IOM	—	743	293	288
UK	546	498	418	375

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

The data of Rothman et al. [404] upon which the recommendations with respect to teratogenesis are based are shown in **table 38**, expressed as vitamin A:energy densities. The original units of the published article are IU per day; these have been converted to micrograms per day by using a conversion factor of 1 IU = 0.3 μg of retinol and then to a density by using the requirement for a nonpregnant* 31- to 50-year-old woman. This gives the most conservative figure for retinol:energy density. The results are not normally expressed in this way. It seems that there is no epidemiological evidence of a teratogenic effect in a normally nourished population with presumably full vitamin A stores when the amounts of vitamin A ingested are up to 1,875 μg/1,000 kcal.

Considering the widespread and severe effects of prior deficiency in moderately malnourished children, their depleted hepatic stores, and the low fat content of the diet on the one hand, and the relative dangers to mothers who exclusively consume any product formulated according to the recommendations made in this paper in early pregnancy on the other hand, it is reasonable to provide as high a level of vitamin A in the diet as possible without reaching a level where there is any evidence of an adverse effect if the diet is consumed by pregnant women. For this reason, **with the use of a fortified-food approach, it is recommended that the diet of moderately malnourished children contain 1,900 μg of retinol/1,000 kcal.** If a food-based approach is used, an increase of 30% over the highest density recommended for a healthy Western child would be appropriate. This would result in a retinol density of 960 μg/1,000 kcal.

It is assumed that when a food-based approach is being advocated, there will also be a vitamin A capsule distribution program for children at risk for vitamin A deficiency and for the moderately malnourished. If such programs are universally in place with a high and verified coverage, the food-based recommendations can be reduced to match the FAO/WHO recommendation of 600 μg/1,000 kcal.

Vitamin D

Signs of vitamin D deficiency commonly occur in

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* The teratogenic effects occur early in pregnancy, before there is any substantial rise in energy requirement

TABLE 38. Vitamin A teratogenicity[a]

Intake — μg/day	Intake— μg/1,000 kcal	No. of pregnancies	Neural tube defects—no. (%)	All congenital defects—no. (%)
0–1,500	< 625	6,410	33 (0.51)	86 (1.34)
1,500–3,000	625–1,250	12,688	59 (0.47)	196 (1.54)
3,000–4,500	1,250–1,875	3,150	20 (0.63)	42 (1.33)
> 4,500	> 1,875	500	9 (1.80)	15 (3.00)

Recalculated from Rothman et al. [404] to express the intake in terms of nutrient densities. Intakes per unit of energy were calculated on the basis of an intake of 2,400 kcal/day for an early pregnancy in an older woman.

children in hot, dry, and dusty areas. These conditions typically occur in a broad band from the Sahara to China and from the Urals to Ethiopia. Some of these signs may be due to phosphate, calcium, or magnesium deficiency, particularly when the deficiency is associated with severe malnutrition (see sections on these nutrients). Nevertheless, classical rickets, responsive to vitamin D, does occur, particularly where the children are not exposed to sunlight for cultural reasons. Exclusively breastfed infants whose mothers have a low vitamin D status can develop vitamin D deficiency [405–407] or even overt rickets [408].

Although there is a lot of “light” in these countries, the large amounts of atmospheric dust coming from the desert reflect most of the UV-B light, so that it is only when the sun is directly overhead that significant UV-B light is available (in Saudi Arabia, monitoring showed a sharp peak of UV from 1100 to 1300 h and almost none outwith these times). During the middle of the day, most people are indoors or completely covered up. Thus, contrary to expectation, rickets is a relatively common condition in desert areas. It is therefore necessary to ensure that the diet has adequate amounts of vitamin D. For adequate absorption, vitamin D, like other sterols,* requires fat in the diet and no substantial small-bowel bacterial overgrowth.

Table 39 shows the vitamin D recommendations for normal, healthy children.

The requirements are quite variable between committees and age groups. The IOM reduced the recommended intakes to about half those of the US RDAs, 10th edition, and this has been endorsed by FAO.

For a supplementary-food approach, it is appropriate to focus on the 6- to 12-month-old child, who is least likely to be exposed to sunlight and has the highest requirements. Therefore, **it is recommended that 11 μg of vitamin D/1,000 kcal be present in the diet**. For a food-based approach, the FAO/WHO level of 7.4 μg/1,000 kcal may be used.

Vitamin K

Vitamin K is obtained mainly from dark-green leafy vegetables. Malnourished children presumably do not consume sufficient dark-green leafy vegetables. Measurement of the carboxylation of the clotting factors in severe malnutrition shows that up to 20% of patients have evidence of mild vitamin K deficiency (unpublished). Vitamin K is synthesized by bacteria in the large intestine, and it was previously thought that this supplied sufficient vitamin K during adult life. It may be that the small intestinal bacterial overgrowth in malnutrition protects against vitamin K deficiency. Patients taking antibiotics that suppress intestinal flora require a dietary source of preformed vitamin K,** and therefore when antibiotics are given the diet should contain adequate amounts of vitamin K.

However, recent evidence shows that there may be insufficient synthesis of vitamin K in many Westerners with osteoporosis, as shown by undercarboxylation of osteocalcin (a sign of vitamin K deficiency) [410]. Furthermore, there are seasonal changes in vitamin K status in the West [411], probably related to seasonal availability of fresh green vegetables [412].

There do not seem to be any data on the normal vitamin K status of African or Asian populations or moderately malnourished children.

The level of vitamin K in F100 and RUTF is 40 μg/1,000 kcal. This is at the level recently proposed by the IOM for older children and is higher than the FAO/WHO recommendation (**table 40**). The reason for the discrepancy is unclear. The reason for the almost tenfold difference between the IOM recommendations for younger and older children seems inexplicable; the documents do not comment upon this.

Because of the low levels of dark-green leafy vegetables, and hence vitamin K, **in the diets of moderately malnourished children, they should be given the amounts of vitamin K in RUTF and F100 (40 μg/1,000 kcal)**, as recommended by the IOM. For a food-based approach, a level of 20 μg/1,000 kcal (the FAO/WHO requirement plus 30%) would probably be adequate.

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* So-called “swelling lipids” (monoglycerides, phospholipids, and fatty acids) are required to expand the bile salt micelles in order to achieve adequate absorption of highly hydrophobic compounds such as many sterols. The bacteria overgrowing the intestine in malnutrition deconjugate bile salts and could drastically reduce vitamin D availability [214, 409].

** Prophylaxis with cotrimoxazole in patients with HIV does not cause suppression of intestinal bacteria.

TABLE 39. Vitamin D RNIs (μg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	7.43	5.23	4.02
IOM	—	7.43	4.89	3.60
UK	10.93	9.96	7.32	0.00

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom

Biotin

Biotin is normally already present in the diet in what are thought to be adequate amounts, although there is considerable variation from one food to another, and relatively few foods have been analyzed. When uncooked egg protein is used in formulating foods for malnourished children, additional biotin is essential to neutralize the antibiotin antinutrient, avidin, contained in the egg [413].

Biotin-deficient infants on prolonged parenteral nutrition have a particular facial distribution of fat, skin lesions similar to those associated with zinc deficiency, candidiasis, and flat affect and are withdrawn; these features are similar to those of both kwashiorkor and severe zinc deficiency. There is thus a possibility of clinical confusion and misdiagnosis; biotin deficiency is rarely considered. However, the most characteristic feature of biotin deficiency is complete hair loss, a phenomenon that is also common in malnourished children. Biotin deficiency has not been looked for in moderately malnourished children, so their biotin status is unknown. The plasma levels are lower in severely malnourished children, and biotin supplementation improves their levels of biotin-dependent enzymes [414–416]. It has been postulated that the abnormal fatty acid profile of malnourished children is related to biotin deficiency [417].

F100 contains a high concentration of biotin (24 μg/1,000 kcal*). Relative to the current recommendations and with the uncertainty surrounding the requirements, it would appear that the levels in F100 may be excessive. The recommendations for normal children are given in **table 41**; the IOM and FAO/WHO levels are identical.

In view of the poor diet of malnourished children and the evidence for biotin deficiency in malnourished children [415], **it is recommended for fortification programs that the diet should contain 13 μg of biotin/1,000 kcal**; for food-based approaches to treating the moderately malnourished, an intake of 10 μg/1,000 kcal is appropriate

TABLE 40. Vitamin K RNIs (μg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	14.87	15.69	16.10
IOM	—	3.72	29.34	39.62

FAO, Food and Agriculture Organization; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake

Pantothenic acid

There has been one report of epidemic pantothenic acid deficiency in malnourished refugees [76]. This occurred in Afghanistan among malnourished people who were given highly refined wheat flour but did not receive the other ingredients of the food basket because of a pipeline break. The patients presented with crippling burning foot syndrome, which was only partially relieved by administration of pantothenic acid; the supplementation totally prevented any new cases from developing.

Pantothenic acid is present in the surrounding membranes of most seed plants, and it was this particular circumstance of consuming highly refined flour that seems to have precipitated widespread clinical deficiency, similar to that seen in Japanese prisoner-of-war camps during the Second World War. Although it is likely that the basic ingredients of the diet will have sufficient pantothenic acid, fortified foods should always contain additional pantothenic acid to ensure an adequate intake for moderately malnourished children. F100/RUTF contain 3 mg of pantothenic acid/1,000 kcal. The RNIs are shown in **table 42**.

The diet for a supplementary-food approach should contain 3 mg of pantothenic acid/1,000 kcal and that for a food-based approach 2.7 mg/1,000 kcal.

Essential fatty acids

Essential fatty acids are important for brain and neural tissue development. The evidence for abnormal development of children on a low intake of essential fatty acids in the Western world is becoming clear, now that more sophisticated methods of examining neural development have been established. This is covered in detail in the companion article in this issue by Michaelsen et al. [2].

Malnourished children have low levels of essential fatty acids, particularly n-3 fatty acids. They also appear to have defects in metabolism of the parent essential fatty acids to more unsaturated and elongated fatty acid derivatives [418–425]. There are also alterations in neurological function in malnourished children that are physiologically similar to those seen in essential fatty acid deficiency, but the relationship of these alterations to essential fatty acid deficiency, although probable, has not been confirmed.

The most salient clinical feature of essential fatty acid deficiency is a dry, flaky skin. This is common in moderately malnourished children; mothers whose children are treated with highly fortified lipid-based spreads

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* In some tables and documents, there appears to be a transcription error. The original biotin level set for F100 was 100 nmol/1,000 kcal (biotin has a molecular weight of 244), which is equivalent to 24 μg/1,000 kcal. Because of the transcription error, the biotin content of F100 is given as 100 μg/1,000 kcal instead of 100 nmol/1,000 kcal. The high level in F100 is not deleterious in any way.

TABLE 41. Biotin AIs (μg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	8.92	8.37	9.66
IOM	—	8.92	8.37	9.66

AI, Adequate Intake; FAO, Food and Agriculture Organization; IOM, Institute of Medicine

TABLE 42. Pantothenic acid AIs (mg/1,000 kcal)

Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
FAO	—	2.68	2.09	2.41
IOM	—	2.68	1.96	2.16

AI, Adequate Intake; FAO, Food and Agriculture Organization; IOM, Institute of Medicine

almost all comment on the change in the texture and appearance of their children's skin. The levels recommended are those found in RUTF and F100.

There is substantial transdermal absorption of essential fatty acids, and in many cultures the mothers anoint their children with local oils, which may affect the essential fatty acid status. It is the practice in India to massage children with mustard seed oil. This is a particularly rich source of essential fatty acids and vitamin E; it is noteworthy that malnourished children in India rarely have the same skin lesions or perineal dermatitis that are widespread in African malnourished children. In the absence of essential fatty acids from the diet, in the event of clinical deficiency, or when there is a problem with fat absorption (due to malabsorption syndrome of any cause), essential fatty acid deficiency can be treated and prevented by anointing the child's skin with oils containing the essential fatty acids.

The recommendations are that the omega-6 fatty acid series should comprise at least 4.5% of energy (5 g/1,000 kcal), the omega-3 fatty acid series should comprise at least 0.5% of energy (0.85 g/1,000 kcal), and the total fat content of the diet used to treat moderately malnourished children should provide 35% to 45% of the dietary energy.

Manganese, chromium, molybdenum, and fluorine

There are far fewer data on the quantities of these essential nutrients required in the normal, moderately malnourished, or severely malnourished child. It is recommended that pending more definitive data, the highest IOM requirements be adopted as the interim recommendations for the moderately malnourished child, with the reservations discussed below (**table 43**).

Fluorine. There are large areas of Africa where the major problem is fluorosis. This occurs throughout the whole of the Rift Valley area. There are also areas of India with endemic fluorosis. It is not recommended that additional fluorine be added to any complementary or other food for use in these areas.

Fluorine: complementary food addition of 0 mg/1,000 kcal.

Manganese. Manganese deficiency in animals gives rise to obesity, teratogenic abnormalities of the inner ear, and epilepsy. Human epileptics have low levels of manganese [426]. Manganese is also associated with iron metabolism. Gross clinical deficiency of manganese in parenterally fed adults is associated with anemia and skin lesions.

The manganese content of RUTF is 0.7 mg/1,000 kcal.* The levels of manganese in the blood of malnourished children were about half of those in control children in all studies that reported manganese levels [427–429]. It would appear to be important to add manganese to the diets of malnourished children. However, no studies of manganese supplementation in malnourished children could be found.

It is recommended that the manganese intake be increased to that recommended by the IOM (1.2 mg/1,000 kcal).

Chromium. Chromium has been implicated in carbohydrate metabolism. The levels are low in children with severe malnutrition. Chromium supplementation appears to improve glucose tolerance in malnourished children [430, 431] and adults [432]. The chemical form of chromium appears to be important. Most inorganic chromium is unavailable, and some valencies of the metal (for example the trioxide) are toxic. In view of the reports of chromium deficiency and glucose intolerance in malnourished children, their diets should contain adequate chromium. However, there are insufficient data to determine the appropriate dose to recommend. Thus, it is recommended that chromium be added to the diets at the level of AIs reported by the IOM. This would result in an intake of 11 μg/1,000 kcal.

Molybdenum. Molybdenum is an essential cofactor in several enzymes involved with energy metabolism and the metabolism of sulfite. There do not seem to be reports of clinical deficiency in humans, although there are reports from farm animals. There seems to be a problem in some areas of nutrient–nutrient interactions with high levels of dietary molybdenum (induction of copper deficiency). It is not recommended that molybdenum be added to the diet in excess of the adequate intake reported by the IOM until the extent and frequency of deficient or excessive intakes are defined. The present recommendation is thus 16 μg molybdenum/1,000 kcal.

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* Manganese was inadvertently omitted from the F100 specifications. This omission was corrected when the derivative RUTFs were formulated.

TABLE 43. AIs of fluorine, manganese, chromium, and molybdenum, expressed per 1,000 kcal

Nutrient	Unit	Authority	7–9 mo	10–12 mo	1–3 yr	4–6 yr
Fluorine	mg	IOM	—	0.74	0.68	0.72
Manganese	mg	IOM	—	0.89	1.17	1.08
Chromium	µg	IOM	—	8.18	10.76	10.80
Molybdenum	µg	IOM	—	4.46	16.62	15.85

AI, Adequate Intake; IOM, Institute of Medicine

Choline

Choline deficiency in animals gives neurological abnormalities and fatty liver. Both of these conditions occur in the malnourished child, and their pathogenesis is at present unexplained. On the current diets, which do not contain any added choline, the fat in the liver is very slow to dissipate, even in children gaining weight rapidly with a high lipid intake [433, 434]. Fatty liver is common in marasmus as well as in kwashiorkor [434], in contrast to traditional teaching. It is possible that choline deficiency could be associated with this abnormal fat accumulation, and the failure of fat accumulation to dissipate could be due to failure to incorporate choline into the current diets. On the other hand, a small, early study of the effect of choline and betaine on fatty liver of kwashiorkor (assessed by liver biopsy) failed to show fat mobilization [277].

The role of choline deficiency in malnutrition awaits further work. In the meantime, it is recommended that the IOM RNI be followed (220 mg/1,000 kcal).

Tolerable upper limits of nutrients for the malnourished

There is considerable uncertainty about the safe upper limits of many of the nutrients that are recommended for addition to the diets of normal, healthy individuals; however, they are in general conservative.

For moderately malnourished children who have abnormalities of intestinal, liver, and renal function that may affect the absorption, metabolism, and disposal of nutrients, there are no data upon which to confidently establish tolerable upper limits. Malnourished children have tissue deficits of most nutrients (except sodium and usually iron) that need to be made good; they need to have sufficient nutrients in the diet to sustain accelerated weight and height gain. This is a totally different situation from the factors that the committees who established the tolerable upper limit recommendations took into account. The upper limits were set for members of the general public who are already replete, may be in the upper section of the intake distribution, or may through individual idiosyncrasy be sensitive to a particular nutrient. For the moderately malnourished, a similar argument of particular sensitivity of the malnourished child has been advanced in this paper for restricting sodium and iron in the diets and, indeed, for setting tolerable upper limits for these two nutrients, in particular, that are more stringent than those for the normal, healthy child living in the developed world. Individuals with other disorders, such as diabetes, cirrhosis, renal failure, hypertension, or an inborn error of metabolism, also have specific changes made to the recommendations to accommodate their clinical conditions that are not addressed by the committees setting tolerable upper limits.

A further consideration is that the safe upper limits are set for *individual* nutrients on the basis that there might be adverse nutrient–nutrient interactions if a particular nutrient was consumed to excess without increments in the interacting nutrient. For example, the upper limit for zinc is set to avoid induction of copper deficiency if copper intake is marginal; similarly, the upper limit for folate is set to avoid neurological damage if vitamin B_{12} intake has been deficient. Such considerations do not obtain when a food that aims to include all essential nutrients in sufficient amounts with the correct balance to avoid such interactions is formulated and given as a complete diet or as a part of a diet that has added *balanced* and complete fortification to compensate for dietary deficiency in the remainder of the diet. When various portions of a supplementary food are consumed, all of the interacting nutrients are then consumed in appropriate ratios. This argument does not apply to a food-based approach, where the chosen diet may not contain enough of one of the interacting nutrients.

Indeed, it is likely that the balance of nutrients is as important as the absolute amounts of each nutrient. Thus, we have considered protein:energy, essential amino acid, copper:zinc, and calcium:phosphorus ratios. However, there are many other important balances that should be considered, such as potassium:sodium:nitrogen:phosphorus:zinc, iron:manganese, iron:selenium, and copper:molybdenum:sulfur ratios. Such interactions are important, and single-nutrient supplementation, if used at all, should always take such interactions into consideration.

A WHO/FAO workshop addressed the problem of defining upper limits for inadequately nourished and diseased populations [435]; the report (sections 3.1.2 and 9) contains the following statements:

> ". . . estimates of upper levels of intake derived for adequately nourished and 'generally healthy' populations may not be appropriate for—or may need adjustments to be useful to—(sub)populations that are nutrient deficient and/or are generally subject to disease conditions such as malaria."

> "The Group came to the conclusion that the appropriateness of a UL established for adequately nourished (sub)populations cannot be assumed to transfer to inadequately nourished (sub)populations. . . . the Group considered it likely that inadequately nourished (sub)populations would need a different set of ULs because of important differences in metabolism and the vulnerability that can result from these differences. However, the Group also concluded that too little is known about the effects of inadequate nutrition on the absorption, distribution, metabolism, and elimination of nutrient substances to allow specification of considerations relevant to adjusting ULs to make them appropriate for inadequately nourished (sub) populations)."

The statements and examples given in this report are germane to consideration of the nutrient requirements of the moderately malnourished. In setting the requirements and the upper limits, it is clear that there is a major problem with the amount, quality, and external validity of the evidence at hand.

Nevertheless, it is appropriate to consider the tolerable upper limits for normal, healthy individuals and to justify any deviation for the moderately malnourished child.

Table 44 gives the tolerable upper levels recommended by IOM for healthy individuals in comparison with the amounts recommended for moderately malnourished children. The recommendations are expressed in terms of both absolute amounts and nutrient densities.

The recommendations for malnourished children exceed the tolerable upper limits recommended by the IOM for four nutrients, when expressed in absolute amounts or as nutrient densities. They are magnesium, zinc, folic acid, and retinol.

It should be noted that the upper limits are set for children within a certain age group. The malnourished child is likely to be lighter and smaller than the children for whom the limits were set. On the other hand, malnourished children are also likely to consume commensurately less of the diet, so that although the nutrient densities have been set on the basis of the energy requirements of normal children and the nutrient intakes of normal children, if less of the food is actually consumed by the children they are less likely to reach the tolerable upper limit.

Magnesium

The tolerable upper limit for magnesium has been set on the basis of the cathartic effect of pharmacological administration of some magnesium salts to adults, with extrapolation to children on a simple weight basis. The WHO/FAO report [435] states that "magnesium ingested as a component of food or food fortificants has not been reported to cause . . . mild osmotic diarrhoea even when large amounts are ingested."

In view of

- The persistently high positive magnesium balance in malnourished children;
- The neglected requirements of magnesium for skeletal growth;
- The lack of any osmotic diarrhea from F100;
- The fact that supplements of magnesium chloride, citrate, acetate, and oxide have been used in the treatment of complicated severe malnutrition for many years (at doses of 24 mg/kg/day);
- The lack of any data from children showing an adverse effect of magnesium;
- The extrapolation from healthy adult recommendations on a simple weight basis rather than the more conventional surface area or metabolic weight basis, which would increase the tolerable upper limit for children considerably; and
- The fact that the recommendation applies only to pharmacological supplementation and not food-incorporated magnesium;

it is suggested that the amount of magnesium to be incorporated into the diet of moderately malnourished children should properly exceed the IOM tolerable upper limit for supplemental magnesium.

Zinc

The largest discrepancy between the recommendations for malnourished children and the tolerable upper limits recommended by the IOM is seen with zinc; therefore, it is worth examining the basis for the tolerable upper limit in relation to the recommendations for the malnourished child.

It is clear from the WHO/FAO report [435] that "the upper level is not meant to apply to individuals who are receiving zinc under medical supervision." It could be argued that the moderately malnourished child is indeed in need of therapeutic quantities of zinc. However, we need to consider what will happen if foods formulated with the present recommendations are consumed by normal, healthy individuals.

No reports were found of adverse effects of intakes of zinc naturally occurring in food that exceeded the upper limit.

The cited adverse effects of zinc are suppression of the immune response, changes in high-density lipoprotein (HDL) cholesterol, interference with iron

TABLE 44. Tolerable upper limits of nutrients in absolute amounts and amounts per 1,000 kcal, in relation to the recommendations for children with moderate acute malnutrition (MAM)

		IOM tolerable upper limits			MAM (food based)			MAM (complement based)			IOM tolerable upper limits				MAM (food based)	MAM (complement based)
		Absolute amount									Amount of nutrient/1,000 kcal					
Nutrient	Unit	7–12 mo	1–3 yr	4–8 yr	7–12 mo	1–2 yr	3–5 yr	7–12 mo	1–2 yr	3–5 yr	7–12 mo	1–3 yr	4–8 yr	Lowest	All	All
Protein	g	—	—	—	16	23	30	17	25	32	—	—	—	—	24	26
Minerals																
Sodium	mg	—	1,500	1,900	370	530	680	370	530	680		1,470	1,370	1,370	550	550
Potassium	mg	—	—	—	950	1,350	1,750	1,050	1,550	2,000	—	—	—	—	1,400	1,600
Magnesium	mg	—	65^a	110^a	**135**	**190**	**250**	**200**	**290**	**370**	—	65^a	80^a	65^a	**200**	**300**
Phosphorus	mg	—	—	3,000	400	570	750	600	860	1,120	—	—	2,160	2,160	600	900
Sulfur	mg	—	—	—	0	0	0	135	190	250	—	—	—	—	0	200
Zinc	mg	5	7	12	**9**	**12**	**16**	**13**	**19**	**25**	7	7	9	7	**13**	**20**
Calcium	mg	—	2,500	2,500	400	570	740	560	800	1,050	—	2,445	1,800	1,800	600	840
Copper	µg	—	1,000	3,000	450	650	850	600	850	1,100	—	980	2,160	980	680	890
Iron	mg	40	40	40	6	9	11	12	17	22	60	40	30	30	9	18
Iodine	µg	—	200	300	135	190	250	135	190	250	—	200	215	200	200	200
Selenium	µg	60	90	150	20	30	35	35	55	70	90	90	110	90	30	55
Manganese	mg	—	—	2	0.8	1.1	1.5	0.8	1.1	1.5	—	—	1.4	1.4	1.2	1.2
Chromium	µg	—	—	—	7	11	14	7	11	14	—	—	—	—	11	11
Molybdenum	µg	—	—	300	10	15	20	10	15	20	—	—	215	215	16	16
Vitamins, water soluble																
Thiamine (vitamin B_1)	µg	—	—	—	400	575	750	670	950	1,250	—	—	—	—	600	1,000
Riboflavin (vitamin B_2)	µg	—	—	—	540	770	990	1,200	1,700	2,250	—	—	—	—	800	1,800
Pyridoxine (vitamin B_6)	µg	—	—	30,000	540	770	990	1,200	1,700	2,250	—	—	21,000	21,000	800	1,800
Cobalamin (vitamin B_{12})	ng	—	—	—	675	960	1,240	1,750	2,500	3,200	—	—	—	—	1,000	2,600
Folate	µg	—	300	400	150	210	270	240	330	**430**	—	—	290	290	220	350
Niacin	mg	—	—	10,000	6	8	11	12	17	22	—	—	7,200	7,200	8.5	18

Ascorbate (vitamin C)	mg	—	400	650	50	70	90	60	90	120	—	390	470	390	75	100
Pantothenic acid	mg	—	—	—	2.0	3.0	3.5	2.0	3.0	3.5	—	—	—	—	2.7	3
Biotin	µg	—	—	—	6.5	9.5	12.5	8.5	12.5	16.0	—	—	—	—	10	13
Vitamins, fat soluble																
Retinol (vitamin A)	µg	600	600	900	**650**	**920**	**1,190**	**1,280**	**1,820**	**2,360**	890	590	650	590	**960**	1,900
Cholecalciferol (vitamin D)	µg	25	50	50	5	7	9	7	11	15	—	50	35	35	7.4	11
Tocopherol (vitamin E)	mg	—	200	300	8	11	14	15	20	25	—	195	215	195	11.5	22
Phytomenadione (vitamin K)	µg	—	—	—	13	20	25	25	40	50	—	—	—	—	20	40

IOM, Institute of Medicine

a. The upper limit for magnesium applies only to supplemental magnesium and not to food magnesium.

The values that exceed the tolerable Upper Limits set by the Institute of Medicine, USA, are shown in bold.

absorption, and reduction of copper status. Immune suppression only occurred when massive doses of zinc were given for prolonged periods, and the cholesterol changes were inconsistent and were ignored by the IOM committee.

The effect of zinc on iron absorption was only observed when the zinc:iron ratio exceeded 3:1 and the two metals were given together in water. When they were given with a meal, no effect of the zinc on iron absorption was observed [436]. When the zinc:iron ratio was increased to 5:1, there was a marked effect upon iron absorption (56% decline), but when the same doses of zinc and iron were given with a hamburger meal, no effect was seen. Since it is proposed that zinc and iron should always be incorporated into the diet together and that the zinc:iron ratio should be well within the limits where no interaction is observed, this adverse consideration does not apply to the present recommendations for the moderately malnourished.

The most important effect of zinc appears to be on copper status. It is critical to point out that all studies that have examined the effect of zinc on copper status have given zinc alone without incorporation of any copper into the supplement.

The upper limit was set on the basis of the study by Walravens and Hambidge [437], who added 4 mg/L zinc to a breastmilk substitute, resulting in a total daily intake of 5.8 mg. This supplement was given to 34 infants from just after birth for 6 months. There was no effect upon plasma copper or any other observed adverse effect. It is important to note that physiologically infants have stores of copper laid down during late pregnancy that can supply their requirements for copper until 6 months of age; therefore, this study may not be appropriate to make any judgment about the effect of zinc on copper status in the infant. Second, this study, correctly, did not attempt to give additional copper to these infants. This study has been used to determine the level at which there is no observed adverse effect of zinc supplementation and to set the tolerable upper limit of zinc accordingly. The dose of zinc used appears to have been arbitrary, and higher levels have not been tested to ascertain if there are no observable effects.

No comparable studies were found of children over the age of 6 months who either had higher doses of zinc for prolonged periods or had their copper status assessed.

On the other hand, very large numbers of children have been given much higher doses of zinc supplements, albeit for short periods of time, while recuperating from acute diarrhea, without adverse effects on copper status having been reported (however, it is not clear from the reports whether the effect upon copper status was appropriately examined in most studies).

F100 supplies about 20 mg of zinc/1,000 kcal and has been given to severely malnourished children for up to

2 months without any adverse effect on copper status, although copper has routinely also been added to the diet at a zinc:copper ratio of 10:1 in order to obviate the known interaction of zinc and copper.

In none of the studies examined by the IOM committee that reported an adverse effect of zinc on copper status were copper and zinc supplements given simultaneously. Dual supplementation is routine in all diets used to treat the malnourished.

It is concluded that copper should always be incorporated into any diet or medication that is supplemented with therapeutic doses of zinc. When this is done, the present IOM tolerable upper limit for zinc should be adjusted to allow sufficient zinc to be incorporated into the diets of malnourished children to properly support accelerated lean tissue synthesis and their immunological and functional recovery; zinc deficiency in this particular group of children is widespread and would not be alleviated if the tolerable upper limit set for the United States was applied to diets designed for the malnourished.

Folic acid

The present recommendations for folate intake exceeds the IOM tolerable upper limit for the older child by only a marginal amount. The limit has been set on the basis that high doses of folic acid can exacerbate and mask the neurological manifestations of vitamin B_{12} deficiency. The level has been set at a deliberately conservative amount because vitamin B_{12} deficiency is commonly found in the elderly in developed countries. This is important. This consideration also applies to populations subsisting on largely vegetarian diets, such as the moderately malnourished. Marginal vitamin B_{12} status appears to be widespread in these populations. However, the need for such a conservative tolerable upper limit is obviated if vitamin B_{12} is given in adequate doses along with the folic acid. In principle, if a diet is being fortified with folate, particularly if the amount of folic acid approaches or exceeds the tolerable upper limit, then vitamin B_{12} should always be incorporated into the diet along with folic acid. This is the case with the present recommendations. It should be routine practice to add vitamin B_{12} to all medications and diets that are fortified with folic acid and given to populations at risk for vitamin B_{12} deficiency.

Vitamin A

Vitamin A toxicity in children causes increased intracranial pressure and bone changes. These effects occur when children are given vitamin A in excess of 5,500 µg per day for prolonged periods [438].

There is widespread vitamin A deficiency in much of the world, and massive doses of vitamin A are distributed intermittently in capsule form to most children in the developing world. The cumulative dose does not exceed the toxic dose reported by Persson et al. [438] for children, although they described only five cases of intoxication.

In view of the limited number of studies designed to study vitamin A toxicity in children, the tolerable upper limit has been set by the IOM by extrapolation from adult values, on a simple weight basis. This value is conservative, and if the extrapolation were on the basis of metabolic weight, liver size, or body surface area, the tolerable upper limit would be higher.

In view of the high prevalence of vitamin A deficiency in moderately malnourished children and the increased mortality among vitamin A–deficient children in the developing world, it is important to have sufficient vitamin A in the diet. The question does arise about the possible danger to children who receive large doses of vitamin A from multiple sources. The RNI should take into account the presence of capsule distribution in the area of distribution.

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Appendix 1. Nutrient densities for normal healthy children

TABLE 45. Nutrient densities for normal, healthy children (RNIs and AIs) 6 months to 5 years of age according to age group, expressed as amount of nutrient/1,000 kcal, using the FAO mean female energy requirement as the denominator for the particular age range quoted by each authority[a]

Variable	Unit	Authority	Age group 1	Age group 2	Age group 3	Age group 4
Age range	—	FAO	—	7–12 mo	1–2 yr	3–5 yr
Age range	—	IOM	—	7–12 mo	1–3 yr	4–8 yr
Age range	—	UK	7–9 mo	10–12 mo	1–3 yr	4–6 yr
Age range	—	WHO/FAO/IAEA	—	7–12 mo	1–2 yr	3–5 yr
Energy	kcal/day	FAO	—	673	956	1,242
Energy	kcal/day	IOM	—	673	1,023	1,388
Energy	kcal/day	UK	641	703	1,023	1,333
All values below are expressed per 1,000 kcal female energy requirement						
Protein						
Protein	g	FAO/WHO 2007	—	10.1	11.1	14.5
Protein	g	FAO 1985	22.3	20.1	15.2	14.6
Protein	g	IOM	—	16.4	12.7	13.7
Protein	g	UK	21.4	21.2	15.2	14.8
Protein	%kcal	FAO	8.9	8.0	6.1	5.8
Protein	%kcal	IOM	—	6.5	5.1	5.5
Protein	%kcal	UK	8.6	8.5	6.1	5.9
Minerals						
Sodium	mg	IOM	—	550	978	864
Sodium (min)	mg	UK	503	491	529	518
Potassium	mg	IOM	—	1,041	2,934	2,737
Potassium (min)	mg	UK	1,099	1,001	818	821
Chlorine	mg	IOM	—	847	1,467	1,369
Chlorine (min)	mg	UK	776	757	817	799
Magnesium	mg	FAO	—	79	63	59
Magnesium	mg	IOM	—	112	78	94
Magnesium	mg	UK	121	114	89	88
Phosphorus	mg	IOM	—	409	450	360
Phosphorus	mg	UK	634	578	285	263
Calcium	mg	FAO	—	595	523	483
Calcium	mg	IOM	—	401	489	576
Calcium	mg	UK	820	747	369	340
Zinc (high)	mg	FAO (high)	—	3.7	2.5	2.5
Zinc (moderate)	mg	FAO (moderate)	—	6.1	4.3	4.1
Zinc (low)	mg	FAO (low)	—	12.5	10.8	9.1
Zinc	mg	IOM	—	4.5	2.9	3.6
Zinc	mg	UK	7.7	7.0	5.1	4.9
Zinc (high)	mg	WHO (high)	—	4.9	3.5	3.1
Zinc (moderate)	mg	WHO (moderate)	—	8.3	5.8	5.2
Zinc (low)	mg	WHO (low)	—	16.5	11.5	10.4
Copper	μg	IOM	—	327	332	317
Copper	μg	UK	496	452	399	429
Copper	μg	WHO	—	892	586	459
Iron (15%)	mg	FAO	—	5.9	4.2	4.8
Iron (12%)	mg	FAO	—	7.4	5.2	5.6
Iron (10%)	mg	FAO	—	8.9	6.3	7.2
Iron (5%)	mg	FAO	—	17.8	13.6	14.5
Iron	mg	IOM	—	16.4	6.8	7.2

continued

TABLE 45. Nutrient densities for normal, healthy children (RNIs and AIs) 6 months to 5 years of age according to age group, expressed as amount of nutrient/1,000 kcal, using the FAO mean female energy requirement as the denominator for the particular age range quoted by each authority[a] *(continued)*

Variable	Unit	Authority	Age group 1	Age group 2	Age group 3	Age group 4
Iron	mg	UK	12.2	11.1	7.0	4.6
Iodine	µg	FAO	—	201	78	89
Iodine	µg	IOM	—	193	88	65
Iodine	µg	UK	94	85	73	75
Iodine	µg	WHO	—	74	94	72
Selenium	µg	FAO	—	14.9	17.8	16.9
Selenium	µg	IOM	—	29.7	19.6	21.6
Selenium	µg	UK	15.6	14.2	15.7	15.0
Selenium	µg	WHO	—	17.8	20.9	19.3
Fluorine	mg	IOM	—	0.74	0.68	0.72
Manganese	mg	IOM	—	0.89	1.17	1.08
Chromium	µg	IOM	—	8.18	10.76	10.80
Molybdenum	µg	IOM	—	4.46	16.62	15.85
Vitamins, water soluble						
Thiamine (vitamin B_1)	µg	FAO	—	446	523	483
Thiamine (vitamin B_1)	µg	IOM	—	446	489	432
Thiamine (vitamin B_1)	µg	UK	312	427	523	525
Riboflavin (vitamin B_2)	µg	FAO	—	595	523	483
Riboflavin (vitamin B_2)	µg	IOM	—	595	489	432
Riboflavin (vitamin B_2)	µg	UK	625	569	628	600
Pyridoxine (vitamin B_6)	µg	FAO	—	595	523	483
Pyridoxine (vitamin B_6)	µg	IOM	—	446	489	432
Pyridoxine (vitamin B_6)	µg	UK	468	569	732	675
Cobalamin (vitamin B_{12})	ng	FAO	—	743	941	966
Cobalamin (vitamin B_{12})	ng	IOM	—	743	880	864
Cobalamin (vitamin B_{12})	ng	UK	625	569	523	600
Folic acid	µg	FAO	—	119	167	161
Folic acid	µg	IOM	—	119	147	144
Folic acid	µg	UK	78	71	73	75
Niacin	µg	FAO	—	5,947	6,276	6,439
Niacin	µg	IOM	—	5,947	5,867	5,763
Niacin	µg	UK	6,245	7,112	8,368	8,252
Ascorbate (vitamin C)	mg	FAO	—	44.6	31.4	24.1
Ascorbate (vitamin C)	mg	IOM	—	74.3	14.7	18.0
Ascorbate (vitamin C)	mg	UK	39.0	35.6	31.4	22.5
Pantothenic acid	mg	FAO	—	2.68	2.09	2.41
Pantothenic acid	mg	IOM	—	2.68	1.96	2.16
Biotin	µg	FAO	—	8.92	8.37	9.66
Biotin	µg	IOM	—	8.92	8.37	9.66
Choline		IOM	—	223	196	180
Vitamins, fat soluble						
Vitamin A	µg	FAO	—	595	418	362
Vitamin A	µg	IOM	—	743	293	288
Vitamin A	µg	UK	546	498	418	375
Vitamin D	µg	FAO	—	7.43	5.23	4.02
Vitamin D	µg	IOM	—	7.43	4.89	3.60
Vitamin D	µg	UK	10.93	9.96	7.32	0.00
Vitamin E	mg	FAO	—	4.01	5.23	4.02
Vitamin E	mg	IOM	—	8.92	5.87	5.04

continued

TABLE 45. Nutrient densities for normal, healthy children (RNIs and AIs) 6 months to 5 years of age according to age group, expressed as amount of nutrient/1,000 kcal, using the FAO mean female energy requirement as the denominator for the particular age range quoted by each authority[a] *(continued)*

Variable	Unit	Authority	Age group 1	Age group 2	Age group 3	Age group 4
Vitamin K	µg	FAO	—	14.87	15.69	16.10
Vitamin K	µg	IOM	—	3.72	29.34	39.62
Amino acids						
His	mg	IOM	—	428	267	254
Ile	mg	IOM	—	575	356	349
Leu	mg	IOM	—	1,244	801	777
Lys	mg	IOM	—	1,191	750	729
Met + Cys	mg	IOM	—	575	356	349
Phe + Tyr	mg	IOM	—	1,124	686	650
Thr	mg	IOM	—	656	407	380
Try	mg	IOM	—	174	102	95
Val	mg	IOM	—	776	470	444
His	mg/g protein	IOM	—	26	21	19
Ile	mg/g protein	IOM	—	35	28	25
Leu	mg/g protein	IOM	—	76	63	57
Lys	mg/g protein	IOM	—	73	59	53
Met + Cys	mg/g protein	IOM	—	35	28	25
Phe + Tyr	mg/g protein	IOM	—	69	54	47
Thr	mg/g protein	IOM	—	40	32	28
Try	mg/g protein	IOM	—	11	8	7
Val	mg/g protein	IOM	—	47	37	32

AI, Adequate Intake; FAO, Food and Agriculture Organization; IAEA, International Atomic Energy Agency; IOM, Institute of Medicine; RNI, Recommended Nutrient Intake; UK, United Kingdom; WHO, World Health Organization

a. High, moderate, and low (Zinc) and percentages (Iron) refer to the bioavailability of these metals from diets of differing quality

Appendix 2: Proposed nutrient intakes for the moderately malnourished expressed in absolute units.

TABLE 46. Proposed nutrient intakes for children with moderate acute malnutrition (MAM) expressed as absolute amounts for comparison with the standard FAO/WHO RNIs and AIs for normal, healthy children

Nutrient (absolute amounts)		FAO/WHO RNIs			MAM (food based)			MAM (complement based)		
Age range	Unit	7–12 mo	1–2 yr	3–5 yr	7–12 mo	1–2 yr	3–5 yr	7–12 mo	1–2 yr	3–5 yr
Energy used as divisor	*kcal*	*673*	*956*	*1,242*	*673*	*956*	*1,242*	*673*	*956*	*1,242*
Protein	g	10.1	11.1	14.5	16	23	30	17	25	32
Nitrogen	g	1.6	1.8	2.3	2.6	3.7	4.8	2.8	4.0	5.2
Minerals										
Sodium	mg	—	—	—	370	530	680	370	530	680
Potassium	mg	—	—	—	950	1,350	1,750	1,050	1,550	2,000
Magnesium	mg	53	60	73	135	190	250	200	290	370
Phosphorus	mg	300	430	560	400	570	750	600	860	1,120
Sulfur	mg	0	0	0	0	0	0	135	190	250
Zinc (high)	mg	2.5	2.4	3.1	—	—	—	—	—	—
Zinc (moderate)	mg	4.1	4.1	5.1	—	—	—	—	—	—
Zinc (low)	mg	8.3	8.4	10.3	9	12	16	13	19	25
Calcium	mg	400	500	600	400	570	740	560	800	1,050
Copper	µg	—	—	—	450	650	850	600	850	1,100
Iron (15%)	mg	6	4	4	—	—	—	—	—	—
Iron (12%)	mg	8	5	5	—	—	—	—	—	—
Iron (10%)	mg	9	6	6	—	—	—	—	—	—
Iron (5%)	mg	19	12	13	6	9	11	12	17	22
Iodine	µg	135	75	110	135	190	250	135	190	250
Selenium	µg	10	17	21	20	30	35	35	55	70
Manganese	mg	—	—	—	0.8	1.1	1.5	0.8	1.1	1.5
Chromium	µg	—	—	—	7	11	14	7	11	14
Molybdenum	µg	—	—	—	10	15	20	10	15	20
Vitamins, water soluble										
Thiamine (vitamin B_1)	µg	300	500	600	400	575	750	670	950	1,250
Riboflavin (vitamin B_2)	µg	400	500	600	540	770	990	1,200	1,700	2,250
Pyridoxine (vitamin B_6)	µg	300	500	600	540	770	990	1,200	1,700	2,250
Cobalamin (vitamin B_{12})	ng	500	900	1,200	675	960	1,240	1,750	2,500	3,200
Folate	µg	80	160	200	150	210	270	240	330	430
Niacin	mg	4	6	8	6	8	11	12	17	22
Ascorbate (vitamin C)	mg	30	30	30	50	70	90	60	90	120
Pantothenic acid	mg	1.8	2	3	2.0	3.0	3.5	2.0	3.0	3.5
Biotin	µg	6	8	12	6.5	9.5	12.5	8.5	12.5	16.0
Vitamins, fat soluble										
Retinol (vitamin A)	µg	400	400	450	650	920	1,190	1,280	1,820	2,360
Cholecalciferol (vitamin D)	µg	5	5	5	5	7	9	7	11	15
Tocopherol (vitamin E)	mg	2.7	5	5	8	11	14	15	20	25
Phytomenadione (vitamin K)	µg	10	15	20	13	20	25	25	40	50

AI, Adequate Intake; FAO, Food and Agriculture Organization ; RNI, Recommended Nutrient Intake; WHO, World Health Organization

a. The values recommended, expressed in nutrient:energy densities, have been back-converted from the recommendations derived to absolute amounts using the average energy requirement for female children within the age range quoted, and rounded.

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Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age

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Abstract

There is consensus on how to treat severe malnutrition, but there is no agreement on the most cost-effective way to treat infants and young children with moderate malnutrition who consume cereal-dominated diets. The aim of this review is to give an overview of the nutritional qualities of relevant foods and ingredients in relation to the nutritional needs of children with moderate malnutrition and to identify research needs. The following general aspects are covered: energy density, macronutrient content and quality, minerals and vitamins, bioactive substances, antinutritional factors, and food processing. The nutritional values of the main food groups—cereals, legumes, pulses, roots, vegetables, fruits, and animal foods—are discussed. The special beneficial qualities of animal-source foods, which contain high levels of minerals important for growth, high-quality protein, and no antinutrients or fibers, are emphasized. In cereal-dominated diets, the plant foods should be processed to reduce the contents of antinutrients and fibers. Provision of a high fat content to increase energy density is emphasized; however, the content of micronutrients should also be increased to maintain nutrient density. The source of fat should be selected to supply optimal amounts of polyunsaturated fatty acids (PUFAs), especially n-3 fatty acids. Among multiple research needs, the following are highlighted: to identify the minimum quantity of animal foods needed to support acceptable child growth and development, to examine the nutritional gains of reducing contents of antinutrients and fibers in cereal- and legume-based diets, and to examine the role of fat quality, especially PUFA content and ratios, in children with moderate malnutrition.

Introduction

Child malnutrition is a major global health problem, leading to morbidity and mortality, impaired intellectual development and working capacity, and increased risk of adult disease. This review will deal with the needs of children between the ages of 6 months and 5 years with moderate malnutrition. Infants below 6 months of age should (ideally) be exclusively breastfed, and if malnourished, will have special needs, which will not be covered here. Moderate malnutrition includes all children with moderate wasting, defined as a weight-for-height between –3 and –2 z-scores of the median of the new World Health Organization (WHO) child growth standards and all those with moderate stunting, defined as a height-for-age between –3 and –2 z-scores. There are no specific recommendations on the optimal treatment of children with severe stunting, but it is assumed that children with severe stunting would benefit from a diet adapted for moderately stunted children, as pointed out in the proceedings of this meeting on the treatment of moderate malnutrition [1]. Throughout this review, we have therefore not distinguished between children with moderate stunting and those with severe stunting.

A recent (2005) analysis by the Maternal and Child Malnutrition Study Group (MCUSG) of data from 388 national surveys from 139 countries [2] has provided new estimates of the global prevalence of underweight, stunting, and wasting among children below 5 years of age, based on the new WHO Child Growth Standards. Of the 556 million children under 5 years of age in low-income countries, 20% (112 million) were underweight, 32% (178 million) were stunted, and 10% (55 million) were wasted, including 3.5% (19 million) who were severely wasted. Thus, about 36 million children are suffering from moderate wasting. Underweight, stunting, and wasting each contributes to

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child mortality and disease burden. Of the almost 10 million deaths annually among children below 5 years of age, it was estimated that the attributable fractions of underweight, stunting, and wasting were 19%, 15%, and 15%, respectively, whereas intrauterine growth restriction and low birthweight accounted for only 3.3%. Altogether, these anthropometric indicators of malnutrition, using −2 z-scores as cutoffs, accounted for 21.4% of child mortality and 21.1% of child disease burden [2]. Of the 14.6% of deaths attributable to wasting, only 4.4% were due to severe wasting, and hence 10.2% of the deaths, or about 1 million, were due to moderate wasting.

The typical diet in populations with a high prevalence of malnutrition consists predominantly of a starch-rich staple, such as a cereal (maize, rice) or tuber (cassava), with limited amounts of fruits, vegetables, legumes, and pulses, and little or no animal-source food. Such a diet is bulky, has a low density of energy and nutrients and a low bioavailability of minerals, and will result in impaired growth, development, and host defense to infections. In addition, introduction of such a diet too early or contamination of the diet will lead to frequent infections, which will further impair nutritional status and, hence, increase the risk of infectious diseases. Young children are also likely to be more sensitive to the effect of antinutrients, e.g., high levels of phytate, which impairs the absorption of several growth-limiting minerals, such as zinc. Infants and young children are especially vulnerable to malnutrition because they have a high growth velocity and also high energy and nutrient needs. Growth velocity up to the age of about 2 years is especially high, and it is also during this period that the brain reaches almost 90% of adult size. Global figures on nutritional status have also shown that malnutrition among children below 5 years of age develops mainly during the period from 6 to 18 months [3]. This period, which is the complementary feeding period, is therefore of special importance and will be given special attention in this review. Breastmilk is not included among the foods discussed in this review, as the importance of breastfeeding, especially for malnourished infants and young children, has been emphasized in many other reviews. In the treatment of moderate malnutrition, it is very important that breastfeeding be continued whenever possible and that the dietary treatment given does not replace breastmilk.

As pointed out in the review by Golden on the nutritional requirements of moderately malnourished children [4], the nutritional needs of a wasted and a stunted child differ. In particular, the time needed to reverse the condition will differ considerably between wasting and stunting. It will often be possible to reverse moderate wasting within 2 to 4 weeks, whereas reversing moderate stunting may take months or years, if it is possible at all. Reversing stunting is easier the earlier treatment is started, and the first 2 years especially seem to be a “window of opportunity.” Thus, the requirements of stunted children may be different for different age groups. The main difference between the requirements of wasted and stunted children will be that wasted children have a higher energy requirement and therefore will also benefit from a higher energy density and a higher fat content of the diet, provided the need for other nutrients is covered. If stunted children, with no wasting, are given a diet with high energy density and high fat content over longer periods, there is a risk that they will develop obesity. However, in populations with a high rate of malnutrition, it is likely that those in the age group from 6 to 24 months would benefit from a relatively high energy density, even if they have not yet developed moderate wasting or are “only” moderately stunted. Thus, a diet with a high energy density could have an important role in preventing moderate malnutrition in such populations. When the need for other nutrients is expressed in relation to energy content, it is likely that the requirements will not differ much between children with moderate wasting and stunting [4, 5]. Other factors might also influence the requirements of a moderately malnourished child. The needs are likely to be different if the child is malnourished because of gastrointestinal problems, with impaired absorption of nutrients, or is malnourished mainly due to recurrent infectious diseases, as compared with a child with malnutrition due mainly to an insufficient diet.

The aim of this review is to identify *foods and ingredients* appropriate to treat moderately malnourished children. These foods should be used to create a *diet* that can fulfill the requirements of moderately malnourished children. Some foods and ingredients of limited availability may only be appropriate as part of home-based diets in specific settings, whereas others could be used in food supplements distributed by international organizations, nongovernmental organizations (NGOs), and governments. In **table 1**, the desirable characteristics of such a diet are outlined, and these characteristics will be discussed in detail in this review. Individual foods and ingredients may fulfill only some of these characteristics. For instance, green leafy vegetables may provide a high content of micronutrients and be a valuable food, although they have low fat and low energy contents.

Nutritional qualities of foods and ingredients

Energy density

The energy density is one of the most important qualities of foods for wasted children. If the energy density is too low, the food becomes too bulky, and the child will not be able to eat adequate amounts. Infants and

TABLE 1. Important characteristics of diets appropriate for children with moderate malnutrition

- High content of micronutrients, especially growth (type II) nutrients
- High energy density
- Adequate protein content
- High protein quality and availability
- Adequate fat content
- Appropriate fat quality, especially n-3/n-6 PUFA content
- Content of some animal-source foods
- Low content of antinutrients
- Low risk of contamination
- Acceptable taste and texture
- Culturally acceptable
- Easy to prepare
- Affordable and available

PUFA, polyunsaturated fatty acid

young children have a limited gastric capacity and an energy requirement per unit body weight about three times as high as adults. If a diet has a very low energy density, even nonmalnourished children may not be able to eat adequate amounts because of the bulkiness of the diet. The energy density is most important for children with wasting, as they have an increased energy need for catch-up growth.

The most important factor influencing energy density is the fat content, as the energy density of fat (9 kcal/g) according to the Atwater factors is more than double that of protein and carbohydrate (4 kcal/g). Another important factor is the water content. A biscuit will typically have an energy density of 4 kcal/g, whereas the energy density is much lower in gruels and porridges given to infants. These will typically have densities between 0.6 and 0.8 kcal/g, but the density may be as low as 0.25 kcal/g if the food is based on only cereal and water [6]. The energy density of gruel and porridge is influenced by the type of flour, the fiber content, the method of processing the flour, how the porridge is cooked, and which ingredients are added. The energy density of a meal is calculated as the crude energy content of the ingredients, without taking into account the fact that some of the energy is not available, such as that of fibers. It is likely that this unavailable fraction is higher in malnourished infants and young children than in healthy adults.

Brown et al. have described in detail how different levels of energy density can influence energy intake and how energy intake is also affected by the number of meals given [7]. The effect of meal frequency and energy density on energy intake was examined in 6- to 18-month-old Peruvian children recovering from malnutrition [8]. The energy densities of the diets were 0.4, 0.7, 1.0, and 1.5 kcal/g. When the number of meals per day (from three to five) was controlled for, the energy intake increased with higher energy densities. However, there were some adjustments, as the children were eating smaller amounts. Although the amount eaten was less with the higher energy densities, the children did not compensate fully. Interestingly, when the energy density increased from 1.0 kcal/g, which is usually considered an adequate energy density, to 1.5 kcal/g, the energy intake per kilogram of body weight increased by approximately 20% to 25%.

In a review of complementary feeding, nine studies comparing energy intake in malnourished children receiving diets with different energy densities were identified [7]. In six of the studies, energy intake was considerably higher when the children were given an energy-dense diet. In most of the studies, the level of the energy density in the low-energy-density diet was about 0.5 kcal/g or lower. However, a study of 5- to 18-month-old malnourished children in Bangladesh compared a diet with an energy density of 0.92 kcal/g with a diet of 1.47 kcal/g and also found an increase (about 50%) in energy intake in the group on the energy-dense diet [9]. Thus, increasing energy densities to above 1.0 kcal/g also resulted in increased energy intake among malnourished children. Several studies have shown that ready-to-use therapeutic foods (RUTFs) are very effective in treating severely wasted children [10–12]. A key characteristic of RUTFs is the very high energy density, about 5 kcal/g. However, in populations with a high rate of malnutrition, it is likely that those in the age group from 6 to 24 months would benefit from a relatively high energy density, even if they have not yet developed moderate wasting or stunting. Thus, an energy-dense diet could have an important role in preventing moderate malnutrition in such populations. In addition to the high energy density, other characteristics, such as the supply of milk protein, the fact that they are nutritionally complete in micronutrients, and the fact that they can be eaten without preparation and that most children like them, are likely to contribute to the effectiveness of RUTFs.

In nonbreastfed 6- to 18-month-old children, the minimum energy density of the diet, assuming three daily meals and a functional gastric capacity of 30 g/kg body weight, has been calculated as between 1.00 and 1.08 kcal/g [13]. If the child receives five meals per day, the minimum values are from 0.60 to 0.65 kcal/g. In the 1980s, Cameron and Hofvander suggested that the energy density of diets given to nonmalnourished children in low-income countries should be considerably higher, between 1.5 and 2.0 kcal/g, to provide enough energy [14]. However, these estimates were based on the energy requirements from 1985 [15], which at that time were about 20% higher than current estimates [16].

Diets with a considerably higher energy density than 1 kcal/g and even 2 kcal/g may be beneficial in treating moderately wasted children. These children have an increased energy need for catch-up, and some will have a poor appetite with an inability to eat large amounts. One of the reasons that RUTFs have been so successful in the treatment of severe wasting is likely to be their high energy density of about 5 kcal/g. However, there is a need for intervention studies examining the potential effects of a high-energy diet given to children with moderate malnutrition. A potential adverse effect of a diet with a high energy density in breastfed infants could be a reduction in breastmilk intake, as shown in two studies [17, 18]. However, other studies could not find such an effect [19, 20].

A high energy density can be achieved by reducing the water content of the food and by adding oils or sugar. It is usually considered to be difficult to produce gruels and porridges with energy densities above 1.5 to 2.0 kcal/g. Reducing the water content will result in foods that are not easy for infants and young children to eat because of inappropriate texture and viscosity, and if sugar and other water-soluble ingredients are added in high amounts, the osmolarity will easily become too high. Preferably, the osmolarity should not be much above 300 mOsm/kg [4]. Adding more oil to the diet will not have these negative effects, but the acceptability of adding considerably higher amounts of oil to the foods given to children with moderate malnutrition should be examined further (see Fat Content, below). However, when high amounts of oils (or other ingredients with "empty calories," such as sugar) are added to the diet, it is very important that the nutrient density in the total diet be adequate. In populations with a high rate of malnutrition, it is likely that those in the age group from 6 to 24 months would benefit from a relatively high energy density, even if they have not yet developed moderate wasting or moderate stunting. Thus, an energy-dense diet could also have an important role in preventing moderate malnutrition in such populations.

Conclusions and recommendations on energy density

- Children with stunting have smaller energy requirements than children with moderate wasting and therefore do not have the same need for foods with a high energy density. The energy density of their food probably should not be much higher than that of food for children without malnutrition.
- Energy densities between 1 and 1.5 kcal/g are recommended for infants and young children with stunting.
- Giving a diet with a high energy density for a long period to stunted children could potentially lead to obesity.
- For children with moderate wasting, foods with energy densities between 1.5 and 2.0 kcal/g should be preferred.
- High energy densities can be obtained by adding fats or oils to the food, which will not increase the osmolarity.

Research recommendations

- Research is needed to further define the optimal energy density among both stunted and moderately wasted children.
- It should be investigated whether energy densities higher than 2.0 kcal/g given to children with moderate wasting have advantages and can increase gain in lean body mass.

Water content

The water content of foods differs considerably, from a very high content in liquid foods to a very low content in dry foods such as biscuits. Semiliquid foods or foods fed with a spoon, such as porridges and mashes, are important in the diet of infants and young children, and here the water content is an important determinant of important characteristics such as energy density and viscosity. High water content in a food reduces the energy density and increases the bulk of the food, and if the water content is too high, it will negatively influence energy intake. On the other hand, low water content will increase the viscosity of the food and may make it difficult for young children to eat.

Foods with very low water content, such as RUTFs or biscuits, have a long shelf-life, since the low water content impairs microbial growth if the food becomes contaminated. The minimum water requirement (the water content not bound to food molecules, expressed as the water activity level) for the growth of microorganisms has been determined [21]. For bacteria it is typically 0.85, and for yeast and molds it is as low as 0.61. The water activity level is 0.99 in fresh meat, 0.95 in bread, 0.3 in biscuits, and 0.2 in milk powder. RUTFs have a water activity level of about 0.4 and a shelf-life up to 2 years.

If foods with low water content are given, such as biscuits, there is a need to cover the water requirements in another way, through drinks. If the child drinks unboiled water, the risk of infections from contaminated water is increased, when compared with a situation where the child will receive water in foods that have been boiled or heated, provided the food is given just after preparation and is not contaminated before consumption. As pointed out in the review by Golden, it is especially important that the water requirement be covered in malnourished children, as they have reduced ability to concentrate urine [4].

Macronutrients

Protein

Dietary protein content and quality are of major importance in the treatment of malnourished children. If the content, quality, or availability is too low, it will limit growth and thereby recovery. If the intake is above the requirement, the surplus protein will be metabolized into energy, which is not an energy-efficient process. A surplus will also produce urea, adding to the renal solute load, which is a problem in malnourished children [4]. Furthermore, too much protein might have a negative impact on appetite [22], which is especially harmful in malnourished children undergoing treatment. In severe malnutrition, a high protein intake might compromise liver function [4], but to what degree this is the case for moderate malnutrition is not known. Finally, protein, especially if it comes from animal sources, is typically an expensive ingredient in a diet, which is another reason for not supplying a surplus of protein.

In deciding the optimal protein content of a diet for moderately malnourished children, both the amount and the quality of protein should be taken into account. In the review by Golden [4], it is suggested that the protein requirement of children with moderate malnutrition should be at least 24 of g protein/1,000 kcal (equivalent to about 9.6 protein energy percent [E%]) and preferably 26 g/1,000 kcal (10.4 E%) and that the protein digestibility-corrected amino acid score (PDCAAS) should be at least 70%. These amounts take into account both the extra needs of moderately malnourished children for growth and the extra allowances needed while they are suffering from infectious diseases. This is considerably higher than that in the recent World Health Organization/Food and Agriculture Organization (WHO/FAO) report on protein requirements [5], which recommended a minimum of 6.9 protein E% on the assumption of a catch-up growth of 5 g/kg per day and 8.9 PE% if 10 g/kg per day is assumed. In a review of the composition of fortified blended foods, we suggested aiming for a protein E% of about 12, taking into account that the food supplement would not cover the whole diet [23]. As suggested in the conclusions of this meeting, it is recommended that the protein E% in diets for children with moderate malnutrition should not be above 15 [1].

Protein quality

High-quality protein is defined as protein that supports maximal growth. The various protein quality indexes include one or more factors related to amino acid profile, digestibility, and the presence of inhibiting or enhancing components in the food ingested.

Previously, the protein efficiency ratio (PER) was the most widely used index for evaluating protein quality. It is defined as body weight gain divided by the amount of test protein consumed by a young growing rat. An important disadvantage of the PER is the differences in growth patterns between rats and humans and the different amino acid requirements [24].

The protein digestibility-corrected amino acid score (PDCAAS) is a more recent method to evaluate protein quality and has been introduced because of the weakness of other indexes such as PER. PDCAAS has been adopted by FAO/WHO as the method of choice for evaluating protein quality in human nutrition [5]. PDCAAS represents the amino acids available after protein digestion, that is, the content of the first limiting essential amino acid in a test protein divided by the content of the same amino acid in a reference pattern of essential amino acids [25]. The index also includes the digestibility of the protein, defined as the true digestibility of the test protein measured in a rat assay [24]:

$$PDCAAS = AAS \times TD,$$

where AAS is the amino acid score and TD is the true digestibility.

The highest PDCAAS value that any protein can achieve is by definition 1.0 or 100%, which means that 100% or more of the requirement of essential amino acids is achieved. A score above 100% should by definition be truncated to 100%, because any amino acids in excess of what is required for building and repairing tissues are catabolized. However, when calculating PDCAAS values of diets or foods with several ingredients, the exact PDCAAS value of these ingredients is important, also when PDCAAS is above 100%. Truncation limits the information provided about the potency of a specific protein source to counteract and balance inferior proteins in mixed diets [25]. Therefore, PDCAAS values above 100% are used in this review without truncating.

There are several limitations that must be considered when using PDCAAS: the validity of using the protein requirement of children in a reference amino acid pattern, and the validity of using true digestibility and the truncation of values above 100%. The reference scoring pattern is based on the amino acid requirements of children older than 1 year [26]. Because the basic data were obtained from children who were recovering from malnutrition, the relevance of these amino acid requirements for healthy children can be questioned. In this review, the fact that the data were obtained from children who were recovering from malnutrition should be seen as an advantage, since the focus is on malnourished children. The reference pattern does not, however, include amino acids that may be important under specific physiological and pathological conditions, such as in children and adults suffering from HIV/AIDS [25]. Another limitation is that the list of the amino acid requirements used to identify the limiting amino acid has only one value for total sulfur amino acids, a group that also includes methionine, which is one of the limiting amino acids in soy [25]. PDCAAS is based on protein input and output and may overestimate the protein quality, as it does not take into consideration amino acids that are left unabsorbed in the ileum and are used by bacteria in the colon instead. Similarly, amino acids that are bound to antinutritional factors and thereby are unavailable for absorption are assumed to be digested when the PDCAAS value is calculated [26]. Different PDCAAS values can be obtained for the same food item because of varying values of amino acids in various food tables. Thus, PDCAAS values for the same food might vary, as seen in **table 2**, in which examples of PDCAAS values of different foods from the literature are given together with values we have calculated.

Calculating the PDCAAS value for a food with two or more ingredients is complicated. It is not enough to know the PDCAAS value for each ingredient if the limiting amino acid is not the same. If that is the case. it is necessary to know the amino acid composition of each of the ingredients, to identify the limiting amino acid in the combined food.

There is strong evidence that adding animal-source foods to diets for moderately malnourished children will improve growth and recovery. This could be due to the higher micronutrient intake or the lower intake of antinutrients, as described in Animal-Source Foods, below. However, it is likely that the improved protein quality also plays an important role. We have therefore calculated how different amounts of milk (skimmed-milk powder) and meat (beef) added to different vegetable-source foods influence PDCAAS values. In **table 3** we have calculated how PDCAAS is influenced by replacing 10%, 25%, or 50% of the *weight* of the vegetable-source food by milk or meat. In **table 4** we have performed the same exercise, but with the *protein content* of the vegetable-source food being replaced by protein from animal-source foods.

When the amount of animal food added is based on protein weight (**table 4**), there is not much difference between the effects of milk and meat on PDCAAS. For the vegetable-source foods with the lowest PDCAAS (wheat, maize, black beans, and cassava), it is only when 50% of the protein is replaced by an animal-source food that the increases are up to a level of 80% or above. If only 25% of the protein is replaced, the PDCAAS values are around 60% or lower. When the calculations are based on the weight of foods (**table 3**), milk has a more pronounced effect on the PDCAAS than meat, because meat contains only 20% protein, as compared with 36% in dry skimmed-milk powder. Adding 25% milk powder brings PDCAAS values to a reasonable level (above 70%), whereas the PDCAAS level when meat is added is only 60% or slightly above for wheat, maize, or black beans.

If the aim is to increase the PDCAAS of a combined vegetable and animal meal or diet to a level of 70%

TABLE 2. PDCAAS values of different foods

Food	PDCAAS (%)—from literature[a]	PDCAAS (%)—our calculations[b]
Animal-source foods		
Beef	92 [25]	94
Egg	118 [25]	
Cow's milk	121 [25]	112
Whey protein concentrate	114–161 [23, 24]	
Skimmed-milk powder	124 [24]	
Vegetable-source foods		
Oats	45–51 [29]	60
Rapeseed meal	46 [30]	
Maize	52 [31]	35
Wheat	54 [31], 42 [25]	37
Cassava	57 [31]	44
Rice	65 [31]	54
Black beans	72 [26]	45
Yam	73 [31]	55
Potato	82 [31]	71
Soybeans	90 [31], 91 [25]	93

a. Sources of protein digestibility-corrected amino acid score (PDCAAS) values are given in square brackets.

b. PDCAAS values were calculated on the basis of data from USDA Nutrient Database [27] and the National Danish Nutrient Database [28] with reference to 2- to 5- year-old children recovering from malnutrition [25].

TABLE 3. PDCAAS values (%) with limiting amino acid in parentheses if various proportions of the *weight* of a cereal, legume, or root are replaced by animal protein

		Milk (dry skimmed milk)			Meat (beef)		
Food item	0%	10%	25%	50%	10%	25%	50%
Wheat	37 (Lys)	55 (Lys)	75 (Lys)	98 (Lys)	49 (Lys)	66 (Lys)	92 (Lys)
Rice	54 (Lys)	75 (Lys)	93 (Lys)	110 (Lys)	70 (Lys)	88 (Lys)	98 (Trp)
Maize	35 (Lys)	56 (Lys)	78 (Trp)	95 (Trp)	50 (Lys)	62 (Trp)	76 (Trp)
Oats	60 (Lys)	73 (Lys)	88 (Lys)	105 (Lys)	69 (Lys)	82 (Lys)	96 (Trp)
Soybeans	93 (Lys)	96 (Lys)	99 (Lys)	106 (Lys/Trp)	95 (Lys)	98 (Lys)	100 (Trp)
Black beans	45 (SAA)	56 (SAA)	71 (SAA)	93 (SAA)	50 (SAA)	60 (SAA)	77 (SAA)
Potato	71 (SAA)	106 (SAA/Thr)	113 (Trp)	112 (Trp)	94 (SAA)	99 (Trp)[a]	96 (Trp)[a]
Cassava	44 (Lys)	85 (Lys)	103 (Thr)	111 (Trp)	74 (Thr)	92 (Thr)	95 (Trp)
Yam	55 (Lys)	96 (Trp)	105 (Trp)	110 (Trp)	78 (Trp)	87 (Trp)	91 (Trp)

PDCAAS, protein digestibility-corrected amino acid score; SAA, sulfur amino acids

a. Values decrease, as trypsin is lower in beef than in soybeans.

TABLE 4. PDCAAS values (%) with limiting amino acid in parentheses if various proportions of the *protein content* of a cereal, legume, or root are replaced by animal protein

Food item	0%	Milk (dry skimmed milk)			Meat (beef)		
		10%	25%	50%	10%	25%	50%
Wheat	37 (Lys)	45 (Lys)	57 (Lys)	79 (Lys)	46 (Lys)	60 (Lys)	84 (Lys)
Rice	54 (Lys)	61 (Lys)	71 (Lys)	88 (Lys)	62 (Lys)	73 (Lys)	93 (Lys)
Maize	35 (Lys)	42 (Lys)	54 (Lys)	75 (Lys+Trp)	43 (Lys)	55 (Trp)	67 (Trp)
Oats	60 (Lys)	65 (Lys)	74 (Lys)	90 (Lys)	66 (Lys)	77 (Lys)	95 (Lys)
Soybeans	93 (Lys)	96 (Lys)	101 (Lys)	107 (Trp)	97 (Lys)	100 (Trp)[a]	98 (Trp)[a]
Black beans	45 (SAA)	51 (SAA)	62 (SAA)	81 (SAA)	50 (SAA)	60 (SAA)	88 (SAA)
Potato	71 (SAA)	76 (SAA)	84 (SAA)	97 (SAA)	75 (SAA)	82 (SAA)	93 (SAA)
Cassava	44 (Lys)	51 (Lys)	62 (Lys)	81 (Lys)	52 (Lys)	64 (Lys+Thr)	80 (Thr)
Yam	55 (Lys)	61 (Lys)	70 (Trp)	84 (Trp)	61 (Trp)	66 (Trp)	75 (Trp)

PDCAAS, protein digestibility-corrected amino acid score; SAA, sulfur amino acids

a. Values decrease, as trypsin is lower in beef than in soybeans.

to 80%, as suggested in the review by Golden [4], then adding about 33% to 40% of the protein content as animal food to vegetable foods with the lowest PDCAAS values would be sufficient. To make a significant impact on growth, a prudent recommendation would be that at least one-third of the protein intake should come from animal products if the staple food has a low PDCAAS.

The calculations made here, combining only two foods, are simple as compared with calculations for the total diet, which typically will contain several other ingredients. These other ingredients could have a lower PDCAAS value, reducing the PDCAAS of the whole diet. But they could also have an amino acid pattern that would complement the pattern of the remaining foods, resulting in a higher PDCAAS of the total diet.

Conclusions and recommendations on protein

- Protein intake and quality are important determinants of growth in the treatment of moderately malnourished children.
- A surplus of protein in the diet may reduce appetite and is an ineffective and costly source of energy
- A high protein quality, i.e., PDCAAS > 70% to 80%, should be aimed for.
- Children receiving a diet with a low PDCAAS would benefit from addition of animal-source foods to the diet. It is suggested that about one-third of the protein intake should come from animal-source foods to make a significant impact on growth.

Fat

Fat content

Fat is an important source of energy for infants and young children. The fat content of human milk is high, with about 50% of the energy coming from fat, underlining that fat requirements are high in early life. After introduction of complementary foods, the fat content of the diet decreases, but there is at present no general agreement about the optimal level of fat in complementary foods and in diets for young children. Several recommendations from high-income countries have stated that there should be no restrictions on fat intake during the first years of life, without giving a minimum level [32]. For complementary feeding of children who are not malnourished, a level of 30 to 45 fat E% has been recommended, including the fat from breastmilk [33]. For foods used in emergencies, a fat content of 30 to 40 E% has been recommended for complementary feeding [34]. In the WHO guidelines for nonbreastfed infants and young children, the amount of fat to be added to a diet, aiming at 30 fat E% in the total diet, has been calculated [13]. If the diet contains no animal-source foods, it is recommended that 10 to 20 g of fat or oil should be added to the diet, while it is recommended that children eating animal-source foods, including whole milk, should only be given an additional 5 g of fat or oil daily, equal to one teaspoon per day.

Two reviews have evaluated the evidence for a negative effect of a low fat energy percentage in the diet of children in low-income countries. Prentice and Paul [35] concluded that many children in low-income countries would benefit from an increased fat intake, and they suggested a minimum level of 20 to 25 fat E%. They were cautious about recommending a much higher intake of fat because of the potential risk of obesity and comorbidities seen in many countries, but this is not likely to be a concern in the treatment of children with moderate malnutrition, where the period of treatment is limited. In an analysis of national data from 19 countries from Latin America, Uauy and coworkers [36] compared food-balance sheets with prevalence rates of underweight, stunting, and wasting in the countries. They found that a diet with less than 22% of energy from fat was likely to restrict growth and also that a low intake of animal fats was likely to have a negative effect on growth.

Fortified blended foods such as corn–soy blend and UNIMIX are given to children with moderate malnutrition. These blends have a low fat content, about 14% to 16% of the energy. They are meant to be distributed with separate provision of oil, but to what extent the oil is added to these fortified blended foods when they are given to infants and young children is not known. In some programs, corn–soy blend is mixed with oil before it is handed out. The reason for not adding oil to the fortified blended foods at production is that they would rapidly become rancid and have a shelf-life of only some weeks. However, if oils with added oxidants are used, the shelf-life is longer.

Children with moderate malnutrition, especially those with moderate wasting, have an increased need for energy for catch-up growth and thus require a diet with a high energy density. A diet with high fat content is therefore likely to be beneficial for these children. It is interesting that foods used for treatment of children with severe malnutrition have a very high fat content. In F100 about 50% of the energy comes from fat, and in RUTFs the percentage of energy from fat is between 50% and 60%.

Given the high energy needs of wasted children and the positive results obtained with foods with a high fat content in the treatment of severe malnutrition, it seems prudent to aim at a fat intake close to the upper limit of the range suggested in the review by Golden [4], which is 45 E% for treatment of moderately wasted children. For children with moderate stunting, who need treatment for longer periods, a fat energy percentage close to the lower limit, which is 35 E%, is probably sufficient.

Conclusions and recommendations on fat content

- A low content of fat in the diet reduces the energy density and total energy intake.
- Diets for moderately malnourished children should aim at a fat energy percentage between 35 and 45, and not go below a minimum level of 30 fat E%.
- When the fat content is increased, there may be a need to also increase the content of other nutrients to avoid a decline in the nutrient density.

Research recommendations

- It is plausible that children with moderate wasting would benefit from a diet with a fat content closer to the upper limit (45 E%), whereas a fat content closer to the lower limit (35 E%) will be sufficient for children with stunting. However, there is a need to perform studies to explore optimal fat content further and to examine how different fat contents influence gain in lean body mass.

Fatty acid composition and content of essential fatty acids

Apart from supplying energy, dietary fat plays an important role in allowing adequate absorption of fat-soluble vitamins and an adequate supply of essential fatty acids. The differences between fat sources with respect to absorption of the fat-soluble vitamins vitamin A, D, and E appear to be small. About 5 g of fat has been found to be needed per meal to provide good bioavailability of vitamin A. The absorption seems to be improved somewhat by fat rich in oleic acid (C18:1), but other oils are probably almost as good [37]. Therefore, we assume the essential fatty acid issue to be the most relevant with respect to moderately malnourished children.

There are two types of essential fatty acids, the n-6 and the n-3 polyunsaturated fatty acids (PUFAs), which in most diets are provided by vegetable oils in the form of linoleic acid (C18:2n-6) and α-linolenic acid (C18:3n-3), respectively. Essential fatty acids may also be supplied from meat and fish in their long-chained forms, arachidonic acid (C20:4n-6), eicosapentaenoic acid (C20:5n-3), and docosahexaenoic acid (C22:6n-3).

According to the Nordic Nutrition Recommendations [38], the fat intake of young children (1 to 2 years) should have a quality that provides 5 to 10 E% as essential fatty acids, including at least 1 E% of n-3 PUFA and have a ratio of n-6 to n-3 PUFA between 3 and 9. The need for essential fatty acids is expected to follow the need for energy, and thus the requirements, expressed in weight of essential fatty acids, are expected to increase during a refeeding phase. The FAO/WHO recommendations from 1994 include a general statement that the ratio of linoleic acid to α-linolenic acid in the diet should be between 5 and 10 [39]. Furthermore, it is stated that during the complementary feeding period and until at least 2 years of age, a child's diet should provide similar levels of essential fatty acids as are found in breastmilk. According to the Codex Alimentarius Standard for Infant Formula [40], the ratio of linoleic acid to α-linolenic acid should be between 5 and 15. These recommendations are based on the range of ratios found in breastmilk. However, the ratio in breastmilk tends to be high (up to 15) in populations where mothers have very low intakes of n-3 fatty acids: below the recommended levels [41]. Thus, it is likely that a range between 5 and 9 is more optimal. It makes most sense to use the ratio between n-6 and n-3 PUFA for fatty acids on the same metabolic level (linoleic acid and α-linolenic acid or arachidonic acid vs. n-3 long-chain PUFA [LCPUFA]). However, most foods except fish have only a limited amount of LCPUFA. For these foods, the linoleic acid/α-linolenic acid ratio is almost identical to the n-6/n-3 PUFA ratio.

Golden in his review suggests that the requirement for n-6 PUFA in moderately malnourished individuals is 4.5 E% (equivalent to 5 g/1,000 kcal) and the n-3 PUFA requirement is 0.5 E% (equivalent to 0.55 g/1,000 kcal) [4]. Thus, these recommendations imply an n-6/n-3 PUFA ratio of 9.

A conditional requirement for n-3 LCPUFA is presently established in premature infants, but more mature infants and older children may also benefit from an intake of preformed n-3 LCPUFA. The n-3 LCPUFAs (eicosapentaenoic acid and docosahexaenoic acid) are more efficiently used for tissue incorporation and specific body functions. In primates, it has been shown that n-3 LCPUFAs supplied to the diet of the pregnant or lactating mother are around 10 times more efficiently incorporated into the fetal or infant brain [41]. Inclusion of a small amount of fish, containing eicosapentaenoic acid and docosahexaenoic acid, in the diet will make a great contribution relative to α-linolenic acid with respect to fulfillment of the n-3 PUFA-requirements of all young children.

Infants and young children in low-income countries who are born with low birthweights and thus poor fetal stores, such as premature infants, may be expected to be especially vulnerable and dependent on a postnatal dietary supply of n-3 LCPUFA. Children in low-income countries may have additional requirements due to environmental stress, such as infections. Therefore, we would suggest that more emphasis be given to secure an optimal intake of n-3 PUFAs for children with moderate malnutrition.

Fat composition of the diet

The diets in most low-income countries consist mainly of basic stable foods—cereals, legumes, and roots. Generally, the content of PUFA in these stable foods is low (except for peanuts and soybeans) (**table 15**). The cereal staples and peanuts have a relative high content of n-6 PUFAs and only very small amounts of n-3 PUFAs. It is thus plausible that the general trend in low-income countries is that the dietary intake of many malnourished children is closer to meeting the recommendations for n-6 PUFAs than those for n-3 PUFAs, and that these diets do not meet the recommended n-6/n-3 ratio. An exception could be populations where, for example, the intake of fish or soy oil is high. Only a few studies have examined the dietary intake of children in low-income countries to an extent that allows adequate assessment of the intake of essential fatty acids. The most important fat sources in 24- to 36-month-old Gambian children have been found to be peanuts and peanut oil, cereals, and palm oil. These sources were found to supply 4.6 E% linoleic acid, sufficient according to recommendations, but only 0.13 E% α-linolenic acid, giving a n-6/n-3 PUFA ratio of almost 30 [35]; this ratio is much higher than 15, which is the upper limit seen in human milk in Western countries and therefore is also the upper limit in the current recommendations for infants [35, 41]. However, in 1- to 5-year-old Chinese children with a high prevalence of stunting, the daily intake of essential fatty acids was found to be low (3.3 E%) but was balanced with respect to the n-6/n-3 PUFA ratio [42]. Other studies have looked at the dietary PUFA supply from breastmilk [43]. These studies show that the n-6/n-3 PUFA ratio in human milk varies considerably between low-income countries, but in some low-income countries it has been found to greatly exceed 15, possibly due to a high and unbalanced intake of n-6 PUFAs in the mothers' diet. Thus, in a population with a low n-3 intake, breastfed infants will also have a low supply of n-3 PUFAs and consequently an increased need when they start complementary foods. Supplementing the diet of the lactating mother with foods containing n-3 PUFAs is therefore a way to improve the n-3 PUFA status of the young child.

Symptoms and effects of insufficient fat intake

The signs of severe n-6 PUFA deficiency are scaly skin, impaired water balance, dehydration, and poor growth [44]; whereas] n-3 PUFA deficiency has less obvious signs, manifesting in neurological symptoms, slow visual maturation, delayed motor skill development, and impaired learning [41]. Furthermore, other studies suggest that essential fatty acid deficiency may result in increased susceptibility to infectious disease, shortened erythrocyte survival, and some changes in the structure and function of the heart, liver, gastrointestinal tract, and other organs.

n-3 LCPUFAs are specifically up-concentrated in the central nervous system. Several studies have shown that the intake of n-3 LCPUFAs may affect the function of the central nervous system during early infancy [41], and that they may also affect cognitive development, attention, and behavior [45, 46]. An effect of docosahexaenoic acid supplementation on cognitive function has been shown in preterm infants, most likely because they are born with small stores of LCPUFAs [47]. As many infants in low-income countries are born with low birthweight to mothers who also have low n-3 PUFA intakes, they are likely to be deficient at birth and would probably benefit from a high n-3 PUFA intake and preferably an intake of eicosapentaenoic acid and docosahexaenoic acid from animal sources.

Only a few well-performed studies have examined the PUFA status of young children in low-income countries [48]. Some of these studies have shown high levels of the essential fatty acid deficiency indicators, and most studies show low levels of docosahexaenoic acid and n-6 PUFAs in plasma or blood cell membranes, when compared with children from high-income countries [48]. In a study comparing 18-month-old children from Cambodia and Italy, the Cambodian children had lower levels of linoleic acid than the Italian children, but their α-linolenic acid levels were comparable to those of the Italian children and their LCPUFA levels were higher [49]. The Cambodian children's higher LCPUFA levels could, however, be because they were still breastfed. Among the Cambodian children, 27% were stunted and 5% were wasted. An intervention with micronutrients resulted in a significant increase in linoleic acid and α-linolenic acid, but not of LCPUFAs, suggesting that their PUFA metabolism was influenced by their poor micronutrient status.

Some of the signs of malnutrition may in part be explained by a lack of PUFAs, e.g., the high infection rate [50] and skin changes [51]. Dry, flaky skin is common in cases of moderate malnutrition, and mothers of children treated with fat-based spreads often comment on the improvement of the skin during treatment [4]. Observational studies from China and Africa have suggested that a high n-6 fatty acid intake combined with a low n-3 fatty acid intake also has a negative effect on both weight gain and linear growth [42, 52]. It is also plausible that low n-3 PUFA intake could cause delayed cognitive development. Verbal learning and memory were improved in an intervention study in South Africa among schoolchildren receiving a bread spread with fish flour from a marine source [53].

Thus, essential fatty acid deficiency could be involved in several of the signs that are seen in malnourished children. However, there is a lack of intervention studies proving that insufficient PUFA intake causes some of the signs seen in children with moderate malnutrition, and that the children in fact would benefit from an extra supply.

Conclusions and recommendations on fat quality

- The intake of PUFAs is likely to be low in children with moderate malnutrition.
- The intake of n-3 PUFAs seems to be especially low, resulting in a high n-6/n-3 PUFA ratio.
- Several of the manifestations in children with moderate malnutrition could be caused by PUFA deficiency, but evidence is lacking.
- It is recommended that diets for moderately malnourished children contain at least 4.5 E% of n-6 PUFA and 0.5 E% of n-3 PUFA.
- The n-6/n-3 ratio in the diet should be below 15 and preferably between 5 and 9.
- Foods with a high n-3 PUFA content, such as soybean oil, rapeseed oil, and fish, should be promoted.

Research recommendations

- Research is needed to define the optimal content of PUFA in diets for children with moderate malnutrition

Carbohydrates

Simple sugars

The most important dietary mono- and disaccharides are glucose, fructose, lactose, and sucrose (sugar). These sugars are good sources of energy and will typically increase the energy density of a diet. Sucrose can be added to foods given to children with moderate malnutrition. The advantages and disadvantages of using sugar are described in a separate section on Sugar under Relevant Foods and Ingredients, below.

Lactose comes mainly from milk and milk products. Lactose maldigestion and intolerance are prevalent in many populations in low-income countries, but symptoms are not common before the age of 3 to 5 years, and lactose maldigestion does not seem to be a major problem in the treatment of malnutrition [54, 55]. Even if malnutrition has a negative effect on the intestinal lactase content, the positive results of treating severely malnourished children with F100, which contains about 21 g of lactose per 100 g of dry F100, suggest that the lactose content of foods given to children with moderate malnutrition is not likely to be a problem. RUTFs also contain a considerable amount of lactose (about 12 g/100 g), which does not seem to cause problems when given to malnourished children. Studies of pigs have suggested that lactose may have a positive effect on growth; it enhances calcium absorption and is likely to have a beneficial luminal effect in the intestine [56]. Breastmilk also has a high lactose content, and it has been suggested that this has a prebiotic effect, i.e., stimulating the growth of a beneficial intestinal flora, as some of the lactose will enter the large intestine and act as indigestible fiber [57]. Lactose enhances the absorption of calcium, magnesium, and perhaps phosphorus in infants [58]. However, there is no evidence that lactose improves calcium absorption in adults [59].

Starch

Starch is the most widespread polysaccharide in the human diet. The main sources are staple foods such as cereals, roots, and tubers. The staple food with the largest amount of starch is maize, but wheat, rice, and potatoes also have high contents of starch. Starch is stored as amylose and amylopectin in granules in plant tubers and seeds [60]. Starch is a polysaccharide carbohydrate consisting of α-1-4 linked glucose monomers. Around 20% to 30% is amylose, a linear glucose polymer, and the remaining 70% to 80% is amylopectin, a branched polymer. The ratio of amylose to amylopectin varies between foods; e.g., some varieties of maize contain over 50% amylose, whereas other varieties have almost none [61].

α-Amylase is a digestive enzyme that breaks down starch to maltose and dextrins. Dextrins are mixtures of linear glucose polymers. Amylose starch is less digestible than amylopectin. Maltodextrin is absorbed as rapidly as glucose but does not have the same sweet taste [62].

A considerable fraction of starch is so-called resistant starch, which is inaccessible to enzymatic digestion. Resistant starch may serve as a substrate for the microflora in the colon, where it is microbially degraded to short-chain fatty acids; therefore, physiologically, resistant starch may be considered a soluble dietary fiber [63]. Some short-chain fatty acids may have anti-inflammatory properties [64, 65] .

Dietary fiber

No universally accepted definition of dietary fiber exists. A useful and generally accepted definition is that dietary fiber consists of nonstarch polysaccharides such as cellulose, hemicellulose, pectin, β-glucans, plant gums, and mucilages. In some definitions of dietary fiber, resistant starch components such as oligosaccharides and inulin and noncarbohydrate components such as lignin, waxes, and chitins are also included. Dietary fibers are also called "nondigestible carbohydrates," especially in relation to the physiological effects of these substances in infants and young children [57].

The most fiber-rich plant foods are unrefined cereals and legumes, including soybeans, beans, lentils, and peas. All plant foods contain both insoluble and water-soluble dietary fibers, although in varying quantities. Insoluble fibers, e.g., celluloses, some hemicelluloses, and lignin, are indigestible or only partially fermented in the large intestine. Insoluble fiber in the diet causes soft stools and shortens intestinal transit time, which may reduce the digestibility and availability of nutrients. Food processing, such as extrusion cooking, can to some degree solubilize insoluble fibers, especially in wheat flour [66]. Soluble fibers, e.g., pectins, gums, and mucilages, are found in all plant foods, especially fruits and vegetables, but in varying amounts. Soluble fibers possesses water-binding properties and are relatively rapidly fermented in the colon. Some soluble dietary fibers, such as inulin, can improve absorption of calcium [67–69].

Diets with a high content of soluble dietary fibers may lead to flatulence due to their relatively rapid fermentation in the large intestine [70]. In particular, a group of oligosaccharides, α-galactosides, typically found in legumes, are digested in the colon by bacteria, resulting in the production of short-chain fatty acids and gases that cause flatulence.

High intake of soluble dietary fibers has been shown to lead to negative effects on energy intake in the short term [71] as well as in longer-term studies [72] in healthy subjects and in malnourished children [73].

There are several studies and reviews dealing with the potential negative effect of dietary fibers on energy intake and growth in infants and children. Dietary fibers may reduce energy intake through a suppressing effect on appetite, and they may increase fecal losses of energy due to reduced absorption of fat and carbohydrate [57]. In a study from the Netherlands of infants and young children receiving a "macrobiotic" diet with a high content of dietary fiber (13 g/day), weight gain and linear growth were reduced considerably as compared with a control group [74]. The diet of these children was high in dietary fiber and low in fat, contained no animal-source foods, and had an overall low energy density; thus, the reason for this lower rate of weight gain in children receiving a macrobiotic diet cannot be attributed only to the high content of dietary fiber.

In an intervention study, 7- to 17-week-old infants were given weaning cereals containing wheat and soybeans or wheat and milk and with different fiber contents [75]. The intake of cereal was significantly lower (34 g/day) in a group with a high content of dietary fibers (8.0%) than the intake (42 g/day) in a group with a low intake of dietary fibers (1.8 g/day). There was no difference in apparent absorption of energy or nitrogen between the groups. More children were withdrawn from the wheat and soybeans group than from the wheat and milk group because the infants refused the cereal or got sick. One-third of the infants with high fiber intake were reported to have gritty stools. The infants in the study were very young and had no major problems from the high-fiber diet, but they had only a limited intake of cereal, with most of their energy coming from infant formula. The significant decrease in energy intake from the cereal and the higher withdrawal among those receiving the high-fiber cereal are worrying in relation to vulnerable malnourished children.

The US reference intake of total dietary fiber for children 1 to 3 years of age is 19 g/day, equivalent to 11 g/1,000 kcal [76]. This is a very high intake and is most likely too high for malnourished children, especially if they have gastrointestinal problems. A previous recommendation from the American Academy of Pediatrics was 0.5 g/kg body weight, which is much less than the US reference intake and only about one-quarter of the Institute of Medicine (IOM) recommendation for children 1 year of age [77]. Another recommendation suggested that from the age of 3 years the dietary fiber intake should be 5 g plus 1 g for each year of age [78].

In a population with a high risk of obesity and diabetes, a high intake of dietary fibers is recommended because of their effects on satiety, improved glucose tolerance, and decreased serum cholesterol and triglycerides [57]. Another reason to recommend a diet with relatively high dietary fiber content to young children in the same societies is to accustom them to a high-fiber diet. However, these arguments are not relevant for children with moderate malnutrition. The total intake of dietary fiber for children with moderate malnutrition should be as low as possible. Children under treatment for severe acute malnutrition with F100 receive a diet with no dietary fiber. Furthermore, breastfed infants receive no fiber. Children with moderate malnutrition typically receive home-made diets based mainly on cereals and legumes, as alternatives are costly. Such home-made foods are relatively high in insoluble dietary fiber.

If the dietary fiber content is very low, it may result in constipation, but that is generally not an issue in children treated for malnutrition. It is recommended that insoluble fibers should be present in low amounts in the diet, because they increase bulk and reduce gastrointestinal transit time. The diet should contain a relatively high proportion of soluble fibers, because of their prebiotic properties, leading to an increased fermentation and support of the growth of a beneficial colonic microflora. It is probable that resistant starch and/or oligosaccharides—or other substrates resistant to digestion in the small intestine of the child with moderate malnutrition—may have prebiotic properties in the child with moderate malnutrition.

Until more evidence is available, it is not possible to give recommendations for an upper level of intake of fibers that will not result in problems for children with moderate malnutrition. In dietary products used for children with moderate malnutrition, the content of fibers, and especially of insoluble fibers, should be kept as low as possible. This is especially important during the first 2 years of life and in children with gastrointestinal problems.

With a cereal-based diet, it is difficult to follow the lowest of the recommendations for fiber intake, which is the American Academy of Pediatrics recommendation of less than 0.5 g/kg body weight per day. Assuming that the energy intake is 100 kcal/kg body weight and that two-thirds of energy intake comes from cereals and legumes, this will be equal to about 20 g of dry cereals and legumes per kilogram of body weight. To fulfill the recommendation of not more than 0.5 g of total fiber per kilogram of body weight, the content of total fibers in the cereals and legumes should be below 2.5%. Thus, this recommendation can only be reached if the stable food is rice (**table 12**) or if the amount of cereals and legumes is reduced.

Conclusions and recommendations on carbohydrates

- Lactose maldigestion and intolerance is generally not a problem in the treatment of children with moderate malnutrition.
- Lactose may improve mineral absorption and have prebiotic effects.
- Starch is an important and cheap source of energy for children with moderate malnutrition.
- Dietary fibers increase bulk and satiety and reduce nutrient and energy digestibility, which may be harmful to children with malnutrition.
- It is unknown to what degree fibers are available as energy in infants and children with moderate malnutrition, especially if they have gastrointestinal problems.
- In infants and children up to 2 years of age, the fiber intake, and especially the intake of insoluble fibers, should be kept as low as possible until further evidence is available.
- There are inadequate data to determine an upper limit for intake of insoluble dietary fibers.
- The content of total dietary fibers and of insoluble fibers should be declared on foods produced to treat children with moderate malnutrition.

Research recommendations

- There is a need to perform studies examining the effects of different levels of fiber intake in children with moderate malnutrition, including measurements of the amount of energy in the stools.
- There is a need for further studies to determine the physiological effects of resistant starch, oligosaccharides, especially α-galactosides, and soluble and insoluble dietary fibers in children with moderate malnutrition.
- Effective methods to lower the fiber content of foods for children with moderate malnutrition should be identified and developed.

Minerals and vitamins

All micronutrients are essential to normal functions of biological processes and human health. However, in this article, emphasis is on those nutrients that are important for growth and whose availability is affected by the food matrix or food processing and that are therefore considered to be of particular importance in children with moderate malnutrition.

Minerals

Iron

Iron is involved in many vital functions in the human body. First, iron is important for oxygen transport. Further, iron is essential to brain function and development, and severe iron deficiency can cause retarded mental development, which may be irreversible [79]. Recently, iron supplementation of children has been shown to increase morbidity and possibly mortality among non-iron-deficient individuals in malaria-endemic areas [80, 81]. It is likely that the harmful effects of iron supplementation have to do with the formulation and higher amounts of iron, and it is conceivable that dietary sources of highly available iron are not harmful.

Dietary iron is present in foods in two main forms: heme iron only in foods of animal origin (with high amounts in liver and red meat) and nonheme iron in both animal and plant foods, mostly in the ferric state. Heme iron and nonheme iron are absorbed through different mechanisms. Heme iron is transported into the enterocyte by the heme receptor, whereas nonheme iron uses the divalent metal transporter (DMT1), which means that dietary ferric iron (Fe^{3+}) must be reduced to ferrous iron (Fe^{2+}) before uptake [82]. Absorption of nonheme iron can be enhanced or inhibited by various dietary components and thus depends on the meal composition. An overview of dietary factors inhibiting or enhancing absorption of nonheme iron is given in **table 5**. The absorption of heme iron is much higher than the absorption of nonheme iron: about 25% for heme iron and less than 10% for nonheme iron. Iron absorption is also influenced by the total iron content in the diet (lower iron content increases absorption efficiency) and by the iron status and physiological state of the individual (low iron stores and pregnancy increase absorption efficiency).

Milk has low iron content, and the absorption of iron from milk is relatively poor. Older studies suggested that calcium in milk had a negative effect on iron absorption, but more recent studies have suggested that this is not the case [83, 84]. Some studies have suggested that cow's milk can induce occult intestinal bleeding in young infants, which may contribute to the negative effect of milk on iron status [85]. However, it seems that the process involved in drying milk eliminates this effect, so that milk products based on powdered milk do not cause bleeding [86].

Zinc

Zinc is essential to growth, synthesis, and maintenance of lean body mass and to the immune functions. Through its position in metalloenzymes, zinc plays a major role in vital processes such as nucleic acid synthesis, protein digestion and synthesis, carbohydrate metabolism, bone metabolism, oxygen transport, and antioxidative defense. Zinc is often the limiting growth nutrient (type II nutrient) in diets in populations with a high prevalence of malnutrition [4]. Accordingly, several studies have shown that zinc supplementation has a positive effect on linear growth [88]. A more recent review could not show a significant effect, but this could be because zinc might not be a limiting nutrient in all the studies included in the meta-analysis [89]. The positive effects of animal-source foods on linear growth in many studies may be partly explained by widespread growth-inhibiting zinc deficiency and the high zinc content and bioavailability in animal foods. Thus, zinc is a key nutrient in diets for children with moderate malnutrition. The absorption of zinc is enhanced at low dietary intakes of zinc.

TABLE 5. Dietary compounds that influence the absorption of nonheme iron[a]

Food	Degree of effect	Active substance
Inhibiting		
Whole-grain cereals and maize	– – –	Phytate
Tea, green leafy vegetables	– – –	Polyphenols
Spinach	–	Polyphenols, oxalic acid
Eggs	–	Phosphoprotein, albumin
Cereals	–	Fiber
Enhancing		
Liver, meat, fish	+++	"Meat factor"
Orange, pear, apple	+++	Vitamin C
Plum, banana	++	Vitamin C
Cauliflower	++	Vitamin C
Lettuce, tomato, green pepper	+	Vitamin C
Carrot, potato, beetroot, pumpkin, broccoli, tomato, cabbage	++/+	
Fermented foods	++	Acids

a. Source: modified from Michaelsen et al. [87].

Good dietary sources of zinc include seafood, meat, nuts, and dairy products. There is a high zinc content in whole-grain cereals, but because of the high content of phytic acid, a strong chelator of zinc, the bioavailability is typically low. Calcium also has a negative effect on zinc availability. Golden has recommended a nutrient density for zinc in food-based diets for moderately malnourished children of 13 mg/1,000 kcal. This level is very high and can be difficult to achieve. Only small freshwater fish (**table 25**) contain more than this level of zinc. Meat and large fish (**tables 24** and **25**) typically have a zinc content considerably below the level of 13 mg/1,000 kcal, and milk has a zinc content of about 6 mg/1,000 kcal. Starchy roots and legumes typically contain between 9 and 12 mg/1,000 kcal. Thus, the nutrient density suggested by Golden [4] can only be reached by supplementation or fortification.

Phosphorus

Phosphorus (or phosphate) forms part of the phospholipids, an essential functional component of cell membranes, and part of high-energy phosphate compounds such as adenosine triphosphate (ATP) and creatine phosphate, the biological energy conservation molecule that is essential to all vital processes. Phosphorus is also an essential component of hydroxyapatite, the main structural bone mineral. Deficiency of phosphorus is common in malnourished children, and severe hypophosphatemia is associated with increased mortality in kwashiorkor [90], although causality has not been shown. Phosphorus deficiency is also likely to cause rickets-like bone changes in malnourished children [4]. Phosphorus is likely to be a limiting nutrient in the treatment of children with moderate malnutrition.

Absorption of dietary phosphorus is high (55% to 70%), relatively independently of dietary composition, and does not appear to be up-regulated at low intakes. Dairy products, meat, poultry, eggs, fish, nuts, and legumes are generally good sources of highly available phosphorus. However, the main form of phosphorus from plant material is phytate, which is resistant to digestion unless enzymatically degraded by phytase. Thus, phosphorus from phytate is only absorbed to a minor degree under normal conditions, and the phytate fraction of phosphorus should therefore be discounted from calculations of total phosphorus requirements [4].

Iodine

Iodine is an essential constituent of the thyroid hormones, which are key components of development and growth. Iodine deficiency causes disorders ranging from enlarged thyroid gland (goiter) to severe irreversible mental and congenital retardation (cretinism). The risk and severity of cretinism are, however, determined by iodine deficiency during fetal life. Milder manifestations of iodine deficiency, including mild mental impairment in childhood, may be reversible by iodine supplementation. Most foods have naturally low iodine contents, since their iodine contents depend on the iodine content of the soil. Seafoods, including seaweeds, are good sources of iodine. Dairy products are also good sources when cattle feed is fortified with iodine. Universal iodization of salt is recommended as the only effective way of controlling iodine deficiency, but providing moderately malnourished children with iodine from salt is a problem, as salt intake should be kept low in children with moderate malnutrition. A better option is therefore to fortify other foods with iodine. An alternative approach in situations where fortified complementary foods are not available is to give infants and young children from 7 to 24 months of age an annual dose of iodized oil supplement [91].

Selenium

Selenium deficiency is prevalent and important in children with moderate malnutrition. Selenium protects against oxidative stress, as the main antioxidant enzyme gluthatione peroxidase is selenium dependent [4]. Selenium deficiency seems to play a role in the development of kwashiorkor, and the prognosis of the disease seems to be related to selenium status [4]. Both plant- and animal-source foods contain selenium in several different forms, which generally are well absorbed. However, the content of selenium in both plant- and animal-source foods depends very much on the content in the soil. It is therefore not possible to give advice as to which foods are important to provide a sufficient selenium intake.

Potassium and magnesium

Malnourished children may have a low potassium and magnesium status, especially if they have lived on a diet with few foods other than rice or highly refined wheat and have suffered from diarrhea, which increases the loss of these minerals [4]. Both potassium and magnesium are growth (type II) nutrients, and deficiency has a negative influence on growth. Deficiency of potassium or magnesium interferes with protein utilization; magnesium deficiency increases the risk of developing potassium depletion, and supplementation with magnesium has shown to improve recovery from malnutrition [4, 92].

These two minerals are mainly situated in the outer layers of cereals, and the levels are reduced considerably by milling. In a study of the potassium and magnesium contents of food commodities used for relief feeding, the potassium content was about 350 to 390 mg/100 g in whole-meal wheat flour and only about 115 to 150 mg/100 g in white wheat flour [93]. The corresponding figures for magnesium were about 100 and 25 mg/100 g, respectively. For comparison, wheat–soy blend and oat meal had potassium and magnesium values close to those of whole-meal wheat flour, and rice had values close to those of white wheat flour. When these values are compared with the recommended nutrient densities suggested by Golden (1,400 mg/1,000 kcal for potassium and 200 mg/1,000 kcal for magnesium), whole-meal wheat flour has a potassium content of about three-quarters and a magnesium content about double these recommended densities, while white wheat flour has values far below these recommended densities.

Vitamins

Water-soluble vitamins

Thiamine. Thiamine plays a central role in normal metabolism of energy, particularly carbohydrate. Thiamine is also involved in neural function. Since the body does not have any storage capacity for thiamine, it needs to be part of the daily diet. Thiamine is widely distributed in foods. Whole-grain cereals, meat, and fish are rich sources, whereas highly refined cereals such as polished rice are poor sources of thiamine. Thus, monotonous diets based on highly refined cereals are associated with a high risk of thiamine deficiency.

Vitamin B_{12}. Vitamin B_{12} is the generic name for a group of compounds called cobalamins. Vitamin B_{12} is essential for normal blood formation and neurological function. It plays an indirect but essential role in the synthesis of purines and pyrimidines, formation of proteins from amino acids, transfer of methyl groups, and carbohydrate and fat metabolism. Through its role in the transfer of methyl groups, it is involved in the regeneration of folate. Therefore, folate deficiency and vitamin B_{12} deficiency may have some of the same signs, but vitamin B_{12} deficiency also has neurological consequences.

Vitamin B_{12} occurs almost exclusively in foods of animal origin. Severe deficiency can cause irreversible developmental delay, including irritability, failure to thrive, apathy, and anorexia [94], which may contribute to the development and manifestations of moderate malnutrition and hinder its treatment.

Vitamin C. Vitamin C (ascorbic acid) is essential for enzymatic hydroxylation and thereby stabilization of collagen. It is an important antioxidant and enhances absorption of nonheme iron. Scurvy, the manifestation of vitamin C deficiency, is common among those not consuming fruits or vegetables, such as refugees. The most important symptoms are nausea and poor appetite and bleeding from gums and joints, as well as joint pains and poor wound healing.

An important aspect of low vitamin C levels in the diet of children with moderate malnutrition is that it is associated with low iron absorption, increasing the risk of iron deficiency. Vitamin C is easily oxidized to inactive forms by exposure to air and to some degree by heat treatment. Thus, postharvest storage and cooking of fruits and vegetables decrease the vitamin C content of the foods dramatically. The best source of vitamin C is fresh fruit.

Fat-soluble vitamins

Vitamin A. Vitamin A is essential to vision, cell differentiation, and the immune response. It occurs in foods as two different groups of compounds: preformed biologically active vitamin A and provitamin A carotenoids. Preformed biologically active vitamin A (retinol, retinoic acid, and retinaldehyde) is only present naturally in foods of animal origin. However, biologically active forms (retinyl palmitate) are used to fortify foods such as margarine, dairy products, and sugar with vitamin A. The provitamin A carotenoids require enzymatic cleavage before they are converted into biologically active forms of vitamin A. These compounds occur in orange- and yellow-colored fruits and vegetables and in dark-green leafy vegetables. Given the poor ability of provitamin A–rich green leaves to improve vitamin A status in humans [95], the vitamin A activity of carotenoids was re-evaluated in the late 1990s [95, 96], and in 2000 the IOM [97] revised the conversion factors and introduced a new retinol activity equivalent (RAE), to replace the former retinol equivalent (RE) (**table 6**). It is still debated whether the bioavailability of vitamin A in green leafy vegetables is even lower [98]. Many food-composition tables use RE as the conversion factor for the carotenoids and thus probably overestimate the contribution of vitamin A from vegetable sources. However, in 2003 *Sight and Life* supported the construction of an updated food-composition table for vitamin A [99], which is available on-line [100].

TABLE 6. Provitamin A conversion factors[a]

Compound	μg/μg RAE[b]	μg/μg RE[c]
All-*trans*-β-carotene, dissolved in oil	2	2
Dietary all-*trans*-β-carotene	12	6
Other dietary provitamin A carotenoids	24	12

a. Source: Institute of Medicine [97].

b. Amount (μg) of provitamin A equivalent to 1 μg of retinol activity equivalent (RAE).

c. Amount (μg) of provitamin A equivalent to 1 μg of the formerly used retinol equivalent (RE).

The bioavailability of provitamin A depends on the food matrix and processing; the bioavailability of carotenoids from raw orange-fleshed fruits is higher than that from cooked yellow or orange vegetables, which is higher than that from raw green leafy vegetables [101]. However, detailed information is not available to include in dietary composition software. In addition, zinc may be required for the conversion of provitamin A carotenoids to vitamin A [102].

Vitamin D. Vitamin D is important for normal bone metabolism, but also for the immune system and other body functions. Vitamin D deficiency is associated with growth retardation and rickets and may be a risk factor for tuberculosis [103]. Sources of vitamin D are sun exposure and dietary intake [87, 103]. In many areas, the most important source is sun exposure. However, in sunny countries, factors such as cultural clothing habits (especially among females) [104], skin pigmentation, and air pollution [105] may reduce the value of sun exposure as a source of vitamin D. As mentioned by Golden [4], atmospheric dust in desert areas may reflect most of the UV-B radiation except for the time around noon, when most people are indoors. Therefore, hypovitaminosis D and rickets are very common even in many sunny countries, and people depend on intake of vitamin D through naturally vitamin D–containing foods, food fortification, or supplementation.

Few food items contain more than small amounts of vitamin D. The best dietary sources are fatty fish (salmon, mackerel, herring, sardines, and oil from fish), eggs, liver, and, where available, vitamin D–fortified foods such as milk and margarine [87, 103]. WHO recommends an intake of 10 μg of vitamin D daily to prevent hypovitaminosis D [87]. For children with moderate malnutrition, the recommended vitamin D density is 13 μg/1,000 kcal [4].

Conclusions and recommendations on minerals and vitamins

- » The content and bioavailability of minerals and vitamins are often poor in diets of children with moderate malnutrition and should be improved.
- » The bioavailability of minerals is influenced by various dietary components that may act as either enhancers or inhibitors.
- » The content of phytate in foods has a strong negative effect on the bioavailability of important minerals, and food-processing methods that reduce the phytate content of foods should be promoted.
- » Fortification or supplementation may be needed to cover the high mineral and vitamin requirements of those with moderate malnutrition.

Research recommendations

- » Research is needed to clarify the effect of the food matrix and food processing on mineral and vitamin availability.

Bioactive substances

Many foods also contain bioactive substances, which are substances that do not meet the definition of a nutrient, but have effects on health outcomes. Among children with moderate malnutrition, the most important bioactive factors are milk peptides, the "meat factor," and phytoestrogens.

Milk peptides

The biological activity of some of the milk peptides has been examined in many animal studies and some human intervention studies. Most of the proposed effects of milk peptides are related to the immune or digestive system [106].

The enzymatic digestion of protein begins in the stomach, once the proteins have been denatured by the gastric acid. It has been speculated that some of the effects of whey or other milk proteins could be caused by peptides formed after digestion in the gastrointestinal tract [107–111].

β-Lactoglobulin constitutes about half of the total whey protein in cow's milk, but it is absent in human milk [112]. Several biological roles of β-lactoglobulin have been suggested but not fully proven. Aside from binding calcium and zinc, it appears that β-lactoglobulin may act as a carrier for retinol. β-Lactoglobulin can protect retinol against oxidation by binding it in a hydrophobic pocket; this action furthermore promotes transport of retinol through the stomach to the small intestine, where it can be transferred to another retinol protein. Another physiological role of β-lactoglobulin is its ability to bind free fatty acids, thus promoting lipolysis [113].

α-Lactalbumin represents around 20% of whey protein in bovine milk and is the major protein in breastmilk (20% to 25% of total protein). α-Lactalbumin has a high content of tryptophan and is a good source of branched-chain amino acids, which may be the reason some studies show that whey can stimulate muscle synthesis (see section on whey powder). Infants fed a protein-reduced formula enriched with α-lactalbumin had satisfactory growth and biochemical values, suggesting adequate protein nutrition from the α-lactalbumin–rich formula, despite its lower total protein content [114]. During the digestion of α-lactalbumin, peptides that have antibacterial and immunostimulatory effects appear to be transiently formed and thereby may aid in protection against infection [115].

The concentration of immunoglobulins is very high in colostrum but is lower in mature milk. The whey fraction of milk seems to contain considerable amounts of immunoglobulin, approximately 10% to 15%, including IgG1, IgG2, IgA, and IgM, whose physiological function is to provide various types of immunity for the calf [113]. Several studies have focused on the effects of treating diarrhea with colostrum-derived bovine immunoglobulins. Positive results have been found in children with acute rotavirus diarrhea and in children suffering from both severe chronic *Cryptosporidium parvum* diarrhea and AIDS. Both groups had significantly less stool output and reduced stool frequency, and the latter group required a smaller amount of oral rehydration solution [116, 117]. Cow's colostrum also improved gut maturation and protected against necrotizing enterocolitis in a model of the immature vulnerable gastrointestinal tract using preterm pigs [118].

Even though lactoferrin represents a rather small portion of whey (0.1 g/L). it may have several significant biological functions. Lactoferrin is an iron-binding protein that can bind two ferric ions and thereby function as a carrier of iron. Lactoferrin has important antibacterial and antiviral properties, which are mainly linked to its iron-binding capacity, thus depriving bacteria of iron essential for growth [119]. Furthermore, lactoferrin has been suggested, based on *in vitro* studies, to have antiviral activity against several human pathogens, including HIV [120–122]. In addition to binding iron, the peptide fragment of lactoferrin has direct bactericidal activity. Finally, lactoferrin has antioxidant activity, which may be due to its ability to bind iron. Free iron contributes to the generation of reactive oxygen species [113].

Whey has a high content of bioactive factors, and it has been suggested that whey could have a beneficial effect, especially on the immune system and on muscle tissue, but there is little evidence from vulnerable groups [23].

The "meat factor"

Meat contains the easily absorbed and highly bioavailable heme iron [123]. In addition, meat proteins (from beef, veal, pork, lamb, chicken, and fish) have been reported to increase nonheme iron absorption, and even relatively small amounts of meat (about 50 g in adults) have been demonstrated to enhance nonheme iron absorption from a low-iron-availability meal with a high phytate content [124]. The enhancement of nonheme iron bioavailability is not an effect of animal protein per se, since casein and egg albumin decrease nonheme iron absorption [125]. The "meat factor" effect originates from the digestion of meat proteins to cysteine-containing peptides, but the exact mechanism by which meat has an enhancing effect on iron absorption has not yet been elucidated. The effect is believed to be caused either by a chelation of iron to minimize precipitation and interaction with absorption inhibitors such as phytic acid, or by a reduction of the insoluble ferric iron to the more soluble and thereby bioavailable ferrous iron, which is more efficiently absorbed by the intestinal epithelial cells [126].

Phytoestrogens

Phytoestrogens are a diverse group of naturally occurring nonsteroidal plant polyphenoloic compounds that have estrogenic and antiestrogenic effects because of their structural similarity to estradiol (17β-estradiol).

Soybean products are the most important source of phytoestrogens, but other legumes, flaxseed and other oilseeds, nuts, and some cereals also contain compounds with phytoestrogenic properties. In soybeans, the dominant compounds with phytoestrogenic properties are isofloavones, mainly genistein, daidzein, and glycitein. Lignans are the primary source of phytoestrogens; they are found in nuts and oilseeds as well as in cereals, legumes, fruits, and vegetables. The isoflavone content of defatted soy flour is about 60% of that of full-fat flour. Soy protein isolate and soy protein concentrate have about half as much total isoflavones as full-fat, roasted soy flour. Soy protein concentrate based on alcohol extraction can remove more than 90% of the isoflavones [127].

Consumption of phytoestrogens (isoflavonoids) may have some hormonal effects, although it is difficult to make firm conclusions from the studies available. Excess consumption of isoflavones during childhood may have a negative effect on male fertility [128] by altering the hypothalamic-pituitary-gonadal axis. However, such a hormonal effect seems to be minor [129]. Consumption of soy-based infant formula has been found to have no adverse effects on growth, development, or reproduction in some studies [130, 131]. One study found that the proportion of female infants with breast-bud tissue during the second year of life was higher among those given soy-based formula than among those who were breastfed or given cow's milk formula. Thus, the decline in infantile breast tissue that was seen in breastfed infants and those fed cow's milk did not occur in the infants fed on soy formula, but the long-term implication of this finding is not known [132]. In recent comments from both the European Society for Paediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) and the American Academy of Pediatrics Committees on Nutrition, it was emphasized that infant formula based on soy protein has only very limited medical indications as an alternative to cow's milk-based infant formula in nonbreastfed infants. They also concluded that there is no firm evidence of negative effects, but the long-term effects are unknown and should be investigated further [133, 134].

Conclusions and recommendations on bioactive substances

» Specific milk proteins and whey protein, which contains many peptides and specific proteins, could have potential relevant beneficial effects, but this has to be proven in children with moderate malnutrition.

» The "meat factor" improves iron absorption considerably, which is an additional benefit of including meat in the diet of children with moderate malnutrition.

» Children with a high intake of legumes, especially soybeans, will have a high intake of phytoestrogens. Although there is no firm evidence of negative effects, the long-term effects are unknown. The content of phytoestrogens should be measured in relevant soybean-containing foods and potential negative effects among children with moderate malnutrition should be studied.

Research recommendations

» Research is needed to determine the potential benefits of adding specific milk proteins to the diets of children with moderate malnutrition.

Antinutritional factors

Antinutritional factors are food constituents that have a negative impact on the solubility or digestibility of required nutrients and thereby reduce the amounts of bioavailable nutrients and available energy in the foods. Food constituents with antinutrient properties may also have beneficial health properties, and the significance of each antinutritional factor has to be considered in the context of the specific diets and the specific nutritional problems in a population.

The most important antinutritional food constituent in diets in low-income countries—in terms of negative nutritional impact—is phytate, which is primarily contributed from cereal staples and secondarily from legumes and other plant foods. Phytate forms insoluble complexes with a range of nutrients and thereby inhibits the absorption of proteins and minerals, in particular iron, zinc, and calcium. Other important antinutritional factors in foods that have a negative nutritional impact in low-income countries are polyphenol compounds, which are present in different forms in fruits, vegetables, pulses, and cereals. One of the most widespread groups of polyphenols with antinutritional properties is the soluble tannins, which are present in, for example, tea. The antinutritional effect of polyphenols is complex formation with iron and other metals and precipitation of protein, which reduces absorbability. In addition, a number of more specific food components are present in some foods and may have more isolated negative nutritional impacts in specific populations eating specific foods.

Phytate (phytic acid)

Inositol phosphates consist of an inositol ring and at least one phosphate group. Inositol hexaphosphate (IP6), which is phytate, functions as a storage compound for phosphorus in seeds and is essential for release of phosphorus during germination. The content of phytate in selected plant-derived foods and the distribution within the grain are shown in **table 7** and **table 8**. In a dietary context, the significance of inositol phosphate as an important antinutrient in cereal and leguminous foods is due to this phosphorus storage function in plant seeds. In seeds, phytate may account for as much as 80% of the total phosphorus content and 1.5% of the dry weight. During germination, phytate is hydrolyzed by endogenous phytase to release phosphate and inositol [135]. In a physiological context, phytate and other phosphorylated inositols (IP1 through IP5) are not alien compounds to humans, as these and other inositol deviates are widely present in very small amounts in most mammalian cells, where they are involved in multiple functions related to cell signaling pathways [136]. The antinutritional effect of phytate in a human diet is caused by the inability of the human digestive system to degrade phytate. The phosphate groups in phytate strongly bind divalent cations of Ca, Fe, K, Mg, Mn, and Zn. The complex of iron and other metal ions with IP4 and IP5 is weaker than that with IP6, and lower inositols have an insignificant inhibiting impact on mineral absorption [137, 138].

TABLE 8. Phytate distribution in morphological components of cereals and legumes[a]

Food	Morphological component	Distribution (%)
Peas	Cotyledon	88.7
	Germ	2.5
	Hull	0.1
Wheat	Endosperm	2.2
	Germ	12.9
	Bran	87.1
Maize	Endosperm	3.0
	Germ	88.9
	Hull	1.5
Brown rice	Endosperm	1.2
	Germ	7.6
	Pericarp	80.0

a. Source: O'Dell et al. [154], Beal and Mehta [155].

TABLE 7. Phytate contents in selected plant-derived foods[a]

Food	Phytate (mg/g dry matter)
Cereal-based	
Wheat	
Refined white wheat bread	0.2–0.4
Whole-wheat bread	3.2–7.3
Unleavened wheat bread	3.2–10.6
Maize	
Flour	9.8–21.3
Maize bread	4.3–8.2
Unleavened maize bread	12.2–19.3
Rice	
Rice (polished, cooked)	1.2–3.7
Other cereals	
Oat porridge	6.9–10.2
Sorghum	5.9–11.8
Legumes and others	
Chickpeas (cooked)	2.9–11.7
Cowpeas (cooked)	3.9–13.2
Black beans (cooked)	8.5–17.3
White beans (cooked)	9.6–13.9
Kidney beans (cooked)	8.3–13.4
Tempeh	4.5–10.7
Tofu	8.9–17.8
Lentils (cooked)	2.1–10.1
Peanuts	9.2–19.7
Sesame seeds (toasted)	39.3–57.2
Soybeans	9.2–16.7
Soy protein isolate	2.4–13.1
Soy protein concentrate	11.2–23.4

a. Source: Greiner and Konietzny [139].

Phytate and lower phosphorylized inositols may be hydrolyzed to lower inositols by enzymatic removal of phosphate groups. Phytases involved in enzymatic dephosphorylation are present in plant seeds, where they can mobilize the stored phosphorus, and phytases are also found in the intestines of some animals, such as rats. However, humans have evolved to have insignificant intestinal phytase activity [140], and the consumption of a phytate-rich diet leaves phytate largely undigested and thus phosphorus unreleased for absorption, and other important nutrients immobilized due to complex formation.

The inhibiting effect of phytate on iron absorption is nonlinear, and the phytate content needs to be reduced to below a threshold phytate content of 100 mg [141] (**fig. 1**) or below a phytate:iron molar ratio of 1:1 [142] to have a significant positive effect on iron absorption. The inhibiting effect of phytate on zinc absorption has recently been modeled based on data from human absorption studies [143], predicting that the inhibiting effect of dietary phytate on zinc absorption is

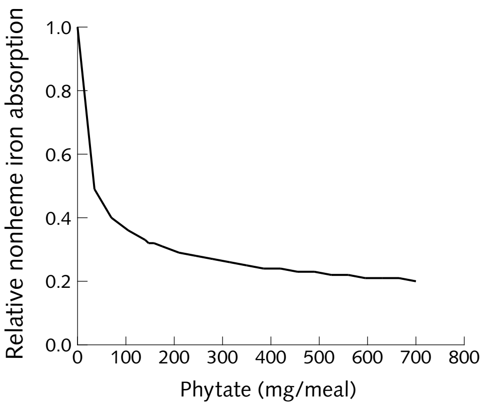

FIG. 1. Effect of phytate content on nonheme iron absorption in a meal without meat or ascorbic acid, expressed relative to a phytate-free meal. Based on algorithms for nonheme iron absorption [141]

linear with no upper threshold for the inhibitory effect [144]. Modeling absorbed zinc as a function of dietary phytate:zinc molar ratios emphasizes the potential benefits of phytate reduction and zinc fortification in diets that are habitually high in phytate.

A plant-based diet has been categorized to have "moderate" zinc availability when the molar phytate:zinc ratio is between 5 and 15 and "low" zinc availability when the molar ratio exceeds 15 [145]. A reduction of the phytate:zinc molar ratio in a maize-based diet from 36 to 17 was shown to significantly improve zinc absorption [146], indicating that—unlike iron absorption—any reduction in phytate may potentially contribute to improving zinc absorption.

Various traditional processing methods can reduce the phytate content in cereals and legumes. The potential impact of traditional processing methods, thermal processing, mechanical processing, fermentation, soaking, and germination (malting) on improving the bioavailability of micronutrients in a plant-based diet was reviewed by Hotz and Gibson [147]. Soaking of cereals and legumes can promote diffusion of phytate into the soaking water. Soaking unrefined maize flour reduced the phytate content by approximately 50% [147], and soaking of legume seeds (peas, peanuts, and pigeon peas) has been reported to reduce phytic acid by about 20% [148, 149]. Soaking may also wash out soluble vitamins and minerals into the soaking water.

Fermentation can reduce phytate by up to as much as 90%, depending on species and pH [147], as a result of the enzymatic activity of microbial phytase originating from the microflora in the fermentation culture, either present on the surface of the fermented foods (spontaneous fermentation) or added as a starter culture. Fermentation can also contribute to activating endogenous phytase in the cereal or legume being processed, especially in fermentation processes producing low-molecular-weight organic acids such as lactic acid, as many endogenous cereal phytases have optimum activity at pH 6 or below [135].

The stimulation of germination of cereals and legumes will activate endogenous phytase as a step in the process of releasing the phosphorus that the plant has stored as phytate. The endogenous phytase activity is higher in wheat and in other nontropical cereals such as rye and barley than in tropical cereals such as maize, millet, and sorghum [150]. Therefore, mixing wheat and maize, for example, in a germination process may stimulate a higher initial phytase activity and lead to higher reduction of phytate as compared with germination of pure maize.

The nutritional benefits of reducing phytate content through processing depend on the ability to reach a sufficiently low level of phytate to improve iron absorption. Dephytinization will also benefit zinc absorption [142] and possibly protein utilization.

In a community-based trial of 6- to 12-month-old children, a complementary food based on millet, beans, and peanuts was phytate reduced by soaking and germination. The phytate content was reduced by 34%, but the molar phytate:iron ratio remained high, being above 11 in the processed food. No impact on iron status in the intervention group was found [151].

In addition to reducing phytate in a plant-based diet through traditional processing technologies, the potential of reducing phytate content in cereal-based foods by adding commercially produced phytase needs to be explored. Commercial phytases have been developed and are commercially available for monogastric animal feed. In particular, in pig production phytase is a widely used additive to enhance protein and phosphorus absorption and thereby growth. The application of commercial phytases to foods for children with moderate malnutrition to reduce phytate and thereby increase nutritional value, particularly mineral bioavailability, is unexplored, and research is needed to clarify the potential for applications, as also pointed out in the reviews in this issue by Golden [4] and by de Pee and Bloem [152]. In a recent study among women, iron absorption from a whole-maize porridge was increased if phytase was added to the porridge [153].

In conclusion, it is important that foods used for rehabilitation of children with moderate malnutrition should have a low content of phytate, especially if there are few or no animal-source foods in the diet. This can be achieved by avoiding unrefined cereals and legumes with high phytate content and by using food-processing methods that reduce the phytate content.

Polyphenols

Polyphenols are classified according to the polyphenolic groups. A major group with antinutritional significance because of inhibition of mineral absorption consists of the phenolic acids classified as hydrolyzable (or soluble) tannins and cinnamic acid derivates (**table 9**). Isoflavones are polyphenols with estrogenic effect (see Phytoestrogens, above), and condensed tannins, another group of flavonoids, have dietary significance by adding an astringent taste, as well as possessing the ability for complex formation with metals similar to soluble tannins.

Soluble as well as condensed tannins are located in the seed coats of dark-colored cereals, such as sorghum and millet, and in beans and other legumes. The tannin content in beans varies with color, with darker beans having a higher content. The tannin content of legumes ranges from a high value of 2,000 mg/100 g in faba beans to a low value of 45 mg/100 g in soybeans.

The antinutritional properties of tannins in human diets are due to complex formation with proteins and with a range of metals, of which complex formation with iron and zinc is the most important in the context of feeding malnourished children. The complex formation immobilizes nutrients for digestion and absorption

TABLE 9. Polyphenol classes[a]

Polyphenol class	Examples of compounds	Examples of sources	Polyphenol content (mg/kg wet weight)	Nutritional significance
Phenolic acids				
Benzoic acid derivates	Hydrolyzable (soluble) tannins, e.g., gallic acid	Tea	Up to 4,500	Inhibitor of mineral absorption
Cinnamic acid derivates	Caffeic acid Chlorogenic acid Ferulic acid	Coffee Fruits Cereals	350–1,750 70–310	Inhibitor of mineral absorption
Flavonoids				
Flavonols	Quercetin	Onion, fruits	350–1,200	
Flavanones	Apigenin	Citrus fruits	200–600	
Isoflavones	Genistein, daidzein, glycitein	Soybeans	580–3,800	Inhibitor of mineral absorption. Estrogenic or/and antiestrogenic effects
Flavanols	Catechin Condensed tannins (proantocyanidins)	Green tea Beans, fruits, wine	100–800 350–550	Astringent taste, inhibiting mineral absorption
Lignans	Linseed			Minor importance

a. Source: modified from Manach et al. [156].

and thereby reduces the nutritional value of the food [157–159]. The tannin complex formation with proteins also inhibits the enzymatic activities of pectinase, amylase, lipase, proteolytic enzymes, β-galactosidase, and those microbial enzymes involved in fermentation of cereal grains [157].

Tannins in legumes reduce ionizable iron absorption by acting as a natural iron-chelating agent. About 50 mg of legume tannin binds about 1 mg of ionizable iron from food [160].

Some condensed tannins possess an astringent taste, which may contribute to a decreased intake of foods containing tannins. Tannin-rich diets have been shown to decrease growth rates in rats, chickens, and ducklings [158], but to what degree this can be a problem in children is not known.

Tannins are heat stable, and thus heat processing does little to reduce the tannin content in plant foods. Soaking in water or in salt solution prior to household cooking significantly reduces the tannin content (by 37.5% to 77.0%), provided the water used for soaking is discarded [158].

Black tea contains high levels of soluble tannins that have a strong inhibiting effect on iron absorption. A study in adult women quantified the inhibition of iron absorption by one cup of tea drunk with a rice meal to be 50%, and drinking two cups reduced absorption by 66% [161]. In some populations, tea, with or without milk, is given to infants and young children. This should be discouraged, and tea should not be given to children with moderate malnutrition.

Other antinutrients

α-Amylase inhibitors

α-Amylase inhibitors are present in many cereals and legumes [162]. Amylase is necessary to hydrolyze starch and is present in the saliva and in the pancreatic secretion. α-Amylase inhibitors reduce starch digestion and energy availability through the inhibition of amylase. Therefore, significant α-amylase inhibitor levels in the diet may prevent required starch digestion, with the result that undigested starch is metabolized in the large intestine as soluble fibers and turned into short-chain fatty acids with lower energy efficiency. α-Amylase inhibitors are relatively resistant to boiling [162]. In a study of rats fed diets with purified α-amylase inhibitors, the utilization of protein and lipids was reduced, the weight of the pancreas was increased, and growth was reduced [163]. To what degree α-amylase inhibitors can also impair growth in children is not known.

Protease inhibitors

Trypsin and chymotrypsin are endopeptidases that break specific bonds in the middle of an amino acid chain, i.e., protein. They are secreted from the pancreas into the small intestine where they reduce large proteins into medium-sized peptides that are further degraded by exopeptidases, which break off amino acids from the ends of the chain. Inhibitors of trypsin and chymotrypsin are present in most legume seeds. Among ordinary food products, soybeans are the most concentrated source of trypsin inhibitors. Trypsin inhibitors may inhibit other proteases beside trypsin [164]. High levels of protease inhibitors may result in increased size of the pancreas and inhibition of growth [165]. Food processing can reduce the content of trypsin inhibitor activity considerably.

Lectins (phytohemagglutinins)

Lectins, also known as phytohemagglutinins are carbohydrate-binding proteins or glycoproteins that are widely distributed in the plant kingdom and are found in most legumes and cereals, primarily localized in the protein bodies of the cotyledon cells.

Lectins are characterized by their ability to agglutinate (clump) red blood cells in various species of animals [165]. They have a unique property of binding carbohydrate-containing molecules [163, 166], thus inhibiting growth by impairing nutrient absorption [165]. In addition, about 60% of the lectins survive transit through the intestinal tract and become bound to the intestinal epithelium, causing disruption of the brush border, atrophy of the microvilli, and reduction in the viability of the epithelial cells. This markedly increases nutrient requirements by the gut. Lectins can also facilitate colonization of the gut by bacteria, including pathogens [167], and can cause bacterial overgrowth of the gut [168]. Like the protease inhibitors, lectins are readily destroyed by moist heat treatment but are quite resistant to inactivation by dry heat treatment or to degradation by digestive enzymes and bacteria [165].

Saponins

Saponins are a large family of structurally similar compounds present in many plants. There has been a special interest in the content in soybeans [169] because of the potential use of saponins as herbal medicine. Saponins have a bitter taste and are characterized by their hemolytic activity and foaming properties. They are hydrolyzed by bacterial enzymes in the lower intestinal tract. Saponins have negative effects on the permeability of the small intestinal mucosa and have been found to impair active nutrient transport in animal and cell models [170, 171]. Whether this effect on the gastrointestinal tract is also relevant for children with moderate malnutrition is not known.

Lysinoalanine

Certain processing methods, such as heat and alkaline treatment, produce lysinoalanine, a cross-linked amino acid. Lysinoalanine is widely distributed in cooked foods, commercial food preparations, and food ingredients. Lysinoalanine may exert a toxic effect via mineral binding in the renal tubules. Conversion of lysine to lysinoalanine may lead to a decrease in the digestibility of the protein and a decrease in biologically available lysine [172, 173], which is important if lysine is the limiting amino acid of a diet. Particular attention has been given to sterilized milk and milk powders, as low-quality milk powders can contain rather large amounts of lysinoalanine [174].

Cyanogenic glycosides

Cyanides are found in many foods and plants and are produced by bacteria, fungi, and algae [175, 176]. Cyanogenic cassava roots (“bitter cassava”) are of particular concern [177]. Cyanide is highly toxic and must be removed. Flour of cyanogenic cassava roots can be soaked in water for activation of enzymatic breakdown of the cyanide compounds. Consumption of insufficiently processed cassava may cause the paralytic disease known as “konzo.”

Conclusions and recommendations on antinutrients

- » The contents of antinutrients in plant-based diets given to children with moderate malnutrition are likely to have a major negative impact on nutrient availability and growth.
- » Animal-source foods have no or very low contents of antinutrients, and a diet with a high content of animal foods will therefore have a low content of antinutrients.
- » Phytate is the most important antinutrient in foods for children with moderate malnutrition because it impairs the bioavailability of iron and zinc and its phosphorus is unreleased for absorption, actions that have a negative effect on growth.
- » In selecting cereals, legumes, and processing methods for diets for children with moderate malnutrition, a low phytate content in the final product should be given high priority.
- » Among the polyphenols, tannins are the most important antinutrients. Legumes and cereals with high contents of tannins should not be given to children with moderate malnutrition. Black tea should not be given to children with moderate malnutrition because of its tannin content.
- » A number of other antinutrients, such as α-amylase inhibitors, protease inhibitors, lectins, saponins, and lysoalanine, can also have a negative effect on growth, although there is a lack of data from malnourished children
- » Cyanides are highly toxic. Cassava should not be given to children with moderate malnutrition, both because of its high cyanide content and because of its low contents of protein and other nutrients.

Research recommendations

- » Commercially produced phytases added to cereals and legumes have been very effective in improving growth in animals, especially in pigs. Their potential for use in foods given to children with moderate malnutrition should be studied.
- » There is an urgent need to perform more research on the potential negative effects of antinutrients in malnourished children, e.g., through observational

studies and animal studies.
- Effective processing methods should be identified and the Codex Alimentarius should provide guidance on acceptable antinutrient contents.

Contaminants

Infants and young children, especially those being treated for wasting, have a very high energy intake per kilogram of body weight and will therefore ingest large amounts of contaminants if they are given food that is contaminated. Furthermore, it is plausible that infants and young children with moderate malnutrition are more vulnerable to the negative effects of pesticides and heavy metals because of their rapid growth and development, but evidence for this is scarce. The use of pesticides is widespread in many low-income countries, and control measures are scarce or lacking. Adulteration of foods is another aspect of contamination with potential serious effects. This recently became evident when it was discovered that melamine had been added to milk in China to increase the nitrogen content and thereby artificially increase the apparent protein content [178]. Melamine can cause urinary calculus, acute renal failure, and death in infants.

Aflatoxins

Aflatoxin is a thermoresistant toxin produced by some molds, especially *Aspergillus flavus*. Aflatoxin may be ingested in contaminated food, inhaled, or absorbed through the skin [179]. Exposure can result in both acute toxicity with lethal outcome or more prolonged effects, such as hepatocarcinosis, depending on the dose ingested [179]. A possible relation between kwashiorkor and aflatoxin exposure has been suggested [179–181]. Studies have also found an association between aflatoxin intake and growth retardation in children [179, 182, 183]. However, a causal relation has not been confirmed [179]. It has been suggested that aflatoxin may have immunosuppressing abilities and synergistic effects with infectious diseases such as malaria and HIV [179].

It is not possible to avoid aflatoxin completely, and the goal is therefore to reduce the contamination and intake as much as possible [179]. Like industrialized countries, several African countries in 2003 had specific mycotoxin regulations to reduce exposure [180]. Some studies from sub-Saharan Africa have shown aflatoxin concentration above the Codex Alimentarius limits in staple foods such as maize and peanuts [180]. Poisoning can still be a serious problem, as illustrated by the large aflatoxinosis outbreak in Kenya in 2004 that resulted in many deaths [179].

High temperature and humidity provide the best environment for fungal growth, conditions that are normal in many tropical countries. With the right conditions, fungi can grow in many different foods and feeds [180]. Typical staples with high risk of contamination are maize and groundnuts [179, 180]. Prevention of aflatoxin exposure, therefore, is primarily accomplished through good agricultural practices, with better handling of crops both before and after harvest, e.g., early harvesting, proper drying, removal of crops from earlier harvest, and proper storage [179, 184].

Conclusions and recommendations on contaminants

- It is especially important that foods used for children with moderate malnutrition have low levels of aflatoxin, as it is likely that these children are more vulnerable to the toxic effects.
- The levels should be at least below the levels allowed by the Codex Alimentarius.
- In programs and teaching material aiming at the treatment of children with moderate malnutrition, it should be emphasized that foods with a high risk of contamination should be avoided.

Food processing

The reasons for processing food include preservation of foods for use in times of shortage; increasing shelf-life; removal of toxins; removal of antinutrients, which will improve digestibility and availability of nutrients; and improvement of palatability. As part of food processing, it is also possible to fortify foods. Food preservation is done in order to reduce the contents of microorganisms and enzymes or to decrease their activity, which can be done by heating, removing water, or adding a preservative such as acid, sugar, or salt.

Processing will typically decrease the contents of vitamins and minerals, but some methods, such as fermentation and germination, can increase the contents of some nutrients, such as vitamins B and C. As processing will also decrease the contents of antinutrients, it will have a positive effect on the availability of vitamins and minerals [185]. Different food processes can have different effects on a number of nutritional qualities. Mensah and Tomkins have written a comprehensive review of how household technologies can be used to improve the nutritional value and safety of complementary foods [186]. They have given a crude rating of how some of the most important of these household methods can have beneficial effects on complementary foods, which is shown in **table 10**. However, more research is needed to fully document the potential benefits of fermentation and other food technologies in treating moderately malnourished children.

In this review, the focus will be on methods used for processing staple foods and legumes and how they influence the contents and availability of nutrients and the contents of fibers and antinutrients, topics that are of special interest for selecting foods for children with moderate malnutrition. There is a wide range of methods from industrial- to household-level methods, and

TABLE 10. Benefits of household food-processing technologies[a]

Benefit	Dehulling	Decortication	Roasting	Soaking	Malting	Fermentation
Organoleptic properties	–	+	+++	+++	++	+++
Detoxification	–	+++	–	+++	–	+++
Energy density	–	+	+	++	+++	+++
Viscosity	–	+	+	++	+++	++
Nutritive value	–	–	+	++	+++	+++
Acceptability	++	++	++	++	+++	+++
Stability	–	–	+++	–	–	+++
Safety	++	+++	++	–	–	+++

a. – No benefit; + below average; ++ average; +++ above average. Source: Mensah and Tomkins [186].

the effect on the nutritional value depends on the kind of staple, the specific food-processing methods, and the intensity of treatment. Some of the most important methods and principles will be explained, and examples of how they influence the nutritional value of the foods will be given. Aspects of food processing will also be covered in the sections on Antinutritional Factors, above, and on Starchy Vegetable Foods, below.

Mechanical methods

Dried staple crops are processed into flours or powders in many different ways, from traditional pounding with pestle and mortar followed by winnowing to advanced industrial milling. The overall principle is to remove the outer layers of the grains, which are either inedible or contain substances that are not wanted because they have negative sensory qualities or antinutritional effects, are toxic, or may have a negative effect on shelf-life.

Most cereals are milled into flour or meal with removal of the outer layers of the grain, which reduces the nutritional value. However, removal of the outer layers also makes the grain more resistant to degradation, because the outer layers of the grains contain fats, which are prone to rancidity. The fiber content is also highest in the outer layers, and milling will therefore reduce the amount of fiber, with lower fiber content with increased milling. The extraction rate is the percentage of the amount of whole-grain cereal that is left after milling. Because the nutrients in cereal grains are unevenly distributed, with higher contents in the outer layers of thiamine, niacin, iron, and calcium especially, milling results in substantial losses of nutrients but also in a reduction in the contents of antinutrients such as fiber, tannins, and phytate (**table 8**). Processing will also reduce the relative content of protein (the protein energy percentage) (**table 12**), as the outer layers of the grain have a higher protein content. The quality of the protein can also be reduced, as the protein in the outer layers can have a high lysine content.

Dehulling or dehusking and decortication are other mechanical methods to remove the outer layers of grains. Dehulling and decortication are often used as synonyms, although strictly speaking dehulling refers to the removal of the outer layer only, whereas decortication removes more layers than only the outer layer.

The optimal degree of milling or the extraction rate is a balance between keeping as much of the nutrients in the finished product as possible and at the same time removing as many of the unwanted substances, such as antinutrients, as possible. It is possible that the optimal extraction rate is different for malnourished children than for the general population, as malnourished children might be more vulnerable to the potential negative effects of antinutrients and fibers. However, because there is a lack of studies evaluating the negative effects of fibers and antinutrients in diets for children with moderate malnutrition, there is a need for studies evaluating how different processing methods for staple foods influence the growth of malnourished children. Milling of the various cereals—wheat, rice, maize, sorghum, and millet—is described in the sections describing the individual cereals below.

Heat processing

Heat can increase the digestibility of protein, carbohydrates, and other nutrients, thereby enhancing the nutritive value of the food. It can also inactivate some of the naturally occurring enzymes, such as pectinase and lipoxygenase, in fruits and vegetables, thereby protecting against off flavors, loss of color, and poor texture in the food product. The heat can release vitamins such as vitamin B_6, niacin, folacin, and certain carotenoids from poorly digested complexes and thereby enhance the bioavailability of these vitamins. Another advantage of thermal processing is inactivation of antinutrients in certain foods. However, thermal processing also has several adverse effects. During thermal processing and subsequent storage, thiamine and ascorbic acid are especially susceptible to depletion due to leaching and thermal degradation. In addition to the Maillard reaction, a chemical reaction between an amino acid and a reducing sugar, forming a variety of molecules responsible for a range of odors and flavors, thermal processing at high temperatures can also cause other undesirable reactions to protein, such as oxidation of amino acids, and formation of new amino acid structures or dipeptides that cannot be digested or absorbed through the normal process [187].

The simplest way of heat-treating cereals, legumes, or tubers is to boil them, but legumes in particular need boiling for a long period to be acceptable for eating, which is a resource-consuming process. This is one of the reasons why cereals and legumes are often heat-treated by roasting. Roasting, also called toasting, is a high-temperature dry treatment that is often used for preparing cereals and legumes for blended foods. Typically the whole grain is heat-treated in a hot drum in which the grain comes into contact with the hot wall. The process reduces some of the antinutrients and reduces the level of protease inhibitors and volatile glycosides [186]. Roasting improves flavor and enhances digestibility of the starch. The attractive "roasted" taste is due to the Maillard reactions in the outer layers of the grain. The process reduces the viscosity of porridge made from roasted flour as a result of dextrinization and starch breakdown [186]. A newer method of roasting, also called "micronizing" or "infrared roasting," brings the heat directly into the grain, somewhat similarly to the microwave principle, and provides a more controlled roasting.

Extrusion cooking (heating under pressure) is an energy-efficient industrial process used widely in the production of blended foods. It is a much more controlled process than roasting and takes only 30 to 60 seconds. This process "precooks" cereals and legumes by breaking down starches and denaturing proteins, thereby improving digestibility. After extrusion cooking, typically at 130° to 140°C and under high shear, the blended food or cereal can be used as an "instant food," which only needs to be mixed with water before eating. However, often it is advised to bring the water to the boiling point before making the porridge or to cook the porridge or gruel for a few minutes in case the water used for mixing is contaminated.

Another important quality of extrusion-treated flours is that the nutrient density is improved because of the lower viscosity, which means that less water is needed to obtain an acceptable viscosity. The lower viscosity is caused by dextrinization, which shortens the starch molecules. Extrusion cooking can only be used for flours or blended foods with a fat content below about 10% if low-cost dry extruders are used, but fat can be added to the product after extrusion.

Extrusion cooking has both positive and negative effects on nutritional value. Positive effects include destruction of antinutritional factors. However, extrusion cooking at very high temperatures and low water content aids Maillard reactions and reduces the nutritional value of the protein. It may also increase the formation of resistant starches, which may lead to intestinal discomfort. Furthermore, heat-labile vitamins may be lost to varying extents [188], but they can be added after extrusion. Lysine is the most sensitive amino acid due to its free ε-amino group, but arginine, cysteine, tryptophan, and histidine may also be affected [189]. Lysine is the limiting amino acid in most cereal proteins, and the fate of this amino acid during extrusion cooking is therefore important.

In a study of healthy adult volunteers receiving a test meal with corn-soy blend cooked for 15 minutes at 80°C, with or without previous extrusion cooking, there was no significant effect on starch digestibility [70]. Furthermore, it was suggested that extrusion-cooked foods caused increased bacterial fermentation in the colon, presumably through the solubilization of insoluble fibers, which may depress appetite. Extrusion cooking has potential advantages when used for blended foods, but the effect of the process on gastrointestinal function in infants and young children with malnutrition needs to be investigated in more detail.

Soaking

Both whole grain and flours can be soaked. Usually the process lasts for 1 or 2 days, but soaking for some hours may also have beneficial effects, such as reduction of phytate content [186]. Soaking of flours results in diffusion of water-soluble minerals but also reduces the content of phytate [147]. The extent of the phytate reduction depends on the type of cereal or legume, the pH, and the length and conditions of soaking. Soaking of unrefined maize flour can reduce phytate content by up to 50%, and most of this reduction takes place during the first few hours of soaking [147]. The contents of other antinutrients, such as saponins, trypsin inhibitors, and polyphenols, are also reduced during soaking [186].

Soaking of grains before milling can improve flavor. If unsafe water is used for soaking, enteropathogenic microbes might multiply and result in a contaminated product. It is therefore important that such foods be boiled long enough to ensure that pathogens are killed.

Germination and malting

Legumes and grains can be soaked in water for up to 24 hours and allowed to germinate or sprout (grow a new shoot). The grains are then dried, dehusked, and milled. In this malting process, some of the starch in the grains is degraded into sugars, protein quality and digestibility are improved, the contents of riboflavin, niacin, and vitamin C are increased, and the contents of antinutrients are reduced [14, 186]. In one study, the content of phytate in a maize flour was reduced by 46% after germination [147]. Malting produces α-amylase, which converts starch into sugars and thereby makes the porridge or gruel less thick. This is of special importance for children with moderate malnutrition, as it allows more cereal or legume to be added, thereby increasing the energy and nutrient density. Several studies have shown that the energy and nutrient intake can be improved if germinated amylase-rich flour is used for porridges or if some of this flour is added to a porridge [20, 186, 190]. Soaking, which is part of the germination and malting processes, can add pathogens to the product, so it should be ensured that the gruel or porridge is heated sufficiently before consumption [186]. In conclusion, germination and malting result in a number of beneficial effects, of which the most important are increased energy and nutrient contents and reduced levels of antinutrients.

Fermentation

Fermentation is one of the oldest and most effective methods of producing and preserving foods. It is a process in which microorganisms, typically lactic acid bacteria or yeast, multiply and produce a number of enzymes, such as amylases, proteases, and lipases, which affect the taste, viscosity, and nutritional value of the product. A crude overview of the beneficial effects of fermentation is given in **table 11**, but some of the effects are not investigated in detail. A very important and well-documented effect is that on food safety, as the low pH and the microorganisms produced during fermentation protect against the multiplication of pathogens.

Fermentation breaks down protein to peptides or amino acids; starch is broken down to simple sugars and phytase is produced, which breaks down phytate. Many foods can be fermented, such as cereals, legumes, roots, fish, meat, and milk. Traditionally and in the household the process is spontaneous, initiated by the microorganisms present in the foods, but in industrial production starter cultures are often used. Fermentation of cereals and animal products is mainly done by bacteria. Molds (multicellular fungi) are used to process cheeses and legumes, whereas yeasts (single-celled fungi) are mainly used in the fermentation of breads.

The fermentation process influences the nutritional quality of foods in a number of ways, e.g., by increasing energy density and increasing the amount and bioavailability of nutrients [191] (**table 11**). Fermentation of cereal gruels can improve protein digestibility. Fermentation of sorghum gruels improved protein digestibility—measured in *in vitro* systems—in gruels made from white (nontannin) as well as colored (high-tannin) sorghum varieties. The relative improvement in protein digestibility due to the fermentation was better in the high-tannin gruels than in gruels made from white sorghum and also than in maize gruels. Protein digestibility increased from 30% to 50% in gruel prepared from dehulled high-tannin sorghum, from 65% to 80% in white sorghum gruel, and from 80% to 85% in maize gruel [191]. Fermentation of cereals has been found to improve the contents of certain B vitamins (thiamine, riboflavin, and niacin). For example, fermentation increased the thiamine content in sorghum from 20 to 47 µg/g and the riboflavin content in pearl millet from 0.19 to 0.36 µg/g [191]. Fermentation can induce degradation of phytate to lower inositol phosphates through microbial phytase enzymes and by activation of endogenous phytases [185]. Fermentation improves the bioavailability of iron and other minerals by reducing phytate content and by lowering the pH. In addition to the beneficial effect of direct fermentation of cereals on mineral absorption, it has been shown that the addition of small amounts of fermented vegetables (specifically, carrots and onions) to a cereal meal (wheat roll) almost doubles the relative iron bioavailability from the meal [191].

TABLE 11. Effects of fermentation on food and potential health benefits

Effect on food	Potential health benefit
Breakdown of starch by amylases	Reduces bulk and increases energy intake
Reduction of phytic acid	Improved absorption of minerals and protein
Decrease in pH	Improved absorption of minerals Improved food safety
Reduction in lactose content (only milk products)	Better tolerance in individuals with lactase deficiency
Increase in lactic acid bacteria	Better food safety Improved gut integrity Potential probiotic effects
Synthesis of B vitamins	Better vitamin B status

In conclusion, fermented foods have many advantages as foods for children with moderate malnutrition and should be promoted where possible.

Cooking in iron pots

Cooking meals in cast-iron pots has been suggested as a sustainable way of providing absorbable iron from meals. Two intervention trials with infants and young children showed that those randomly assigned to eating meals cooked in iron pots had a decreased prevalence of anemia after 8 to 12 months as compared with those assigned to eating meals cooked in noniron pots [192, 193]; however, a more recent study showed no effect of cooking in iron pots on anemia prevalence [194]. An *in vitro* study of the release of iron into a maize porridge prepared in a cast-iron pot showed that both a low pH and the presence of organic acids increased the amount of absorbable iron released from the pot [195]. With low pH and addition of citrate, as much as 26.8 mg of iron/100 g of porridge was released. Even with a neutral pH and with no addition of organic acids, 1.7 mg/100 g porridge or 34 mg/1,000 kcal was released, assuming an energy density of the porridge of 0.5 kcal/g. Thus, the use of cast-iron pots for cooking food for moderately malnourished children has the potential of providing a low-cost, sustainable supply of dietary iron. However, the acceptability of using cast-iron pots in households, the risk of providing too much iron if iron pots are used for fermented foods with low pH, and the risk of heavy-metal contamination should be investigated further.

Conclusions and recommendations on food processing

- Food processing, especially of staple foods such as cereals, legumes, and roots, can have important beneficial effects on the nutritional value of foods given to children with moderate malnutrition.
- The outer layers of grains typically have a high content of both nutrients and antinutritional factors such as phytate, tannins, and fibers. Processes such as milling will therefore remove both nutrients and antinutrients. The optimal degree of milling is therefore a balance between keeping a high content of nutrients and removing as many of the antinutrients as possible, and it is likely that the optimal balance is different for moderately malnourished than for well-nourished children.
- Methods such as soaking, malting, and fermentation increase the nutritional value of foods, e.g., by reducing the content of antinutrients.
- As part of food processing, it is possible to fortify foods with minerals and vitamins.

Relevant foods and ingredients

Starchy vegetable foods

Cereals

Cereals are mainly grasses cultivated for their edible grains or fruit seeds. Cereals are the cheapest way to provide energy. In low-income countries, these foods provide 70% or more of the energy intake [196]. The most important staple foods in terms of global production are maize, wheat, and rice.

Cereal grains supply energy mainly as starch. They are also an important source of protein, supplying most of the protein intake in many populations. They contain from 6 to 14 g of protein/100 g dry weight, and from 7% to 14% of the energy comes from protein. The amino acid composition of cereals is in most cases not optimal, typically being deficient in lysine. There is some calcium and iron, but the absorption of these minerals is not high. They are important sources of B vitamins but contain no vitamin C and no provitamin A, except for whole yellow maize. The amount of fat in cereals is generally low, with a predominance of n-6 PUFAs. Whole grains contain high levels of dietary fiber and antinutrients, which can be reduced by food-processing methods such as milling. The outer layers of cereal grains contain the highest amounts of nutrients, fibers, and antinutrients. Processing methods such as milling will therefore typically reduce the contents of all these three constituents. The degree of processing is therefore a balance between reducing the negative factors (antinutrients and fibers), which is important for young children, especially if they are malnourished, and not removing too much of the nutrients. This balance is different for each cereal and will be discussed in the sections below. It is possible that the optimal extraction rate is different for malnourished children than for the general population, as malnourished children might be more vulnerable to the potential negative effects of antinutrients and fibers. If a large fraction of the whole grain is removed, such as in white wheat flour where 30% to 40% of the whole grain is removed, this will also influence the price of the product.

Some cereals, especially wheat, rye, and barley, contain gluten, which can cause celiac disease, a form of gluten allergy. Oats may contain very small amounts of gluten. Most other cereals, including maize, the most widely used cereal in food aid, do not contain gluten. Until recently it was believed that celiac disease or gluten intolerance only affected people of European origin. However, new studies have shown that celiac disease is also a problem in populations in Southern Asia, the Middle East, North, West, and East Africa, and South America whose main staple food is wheat [197]. In a study of the prevalence of celiac disease in Egypt, 4.7% of children admitted with diarrhea or failure to thrive had celiac disease [198]. Thus, gluten intolerance should also be considered in children with moderate malnutrition from populations with a high intake of wheat. In such populations, the use of diets with no gluten should be considered if the prevalence of celiac disease is high.

Wheat

Wheat is one of the cereals that are produced in the highest quantities in the world, and it is also the main staple food in some low-income countries, e.g., in North India and North Africa [196, 199]. The protein content is about 10 g/100 g, i.e., the protein content constitutes about 12% of the energy. However, the quality of the protein is lower than in other cereals, with a relatively low PDCAAS (**table 2**). Lysine is the limiting amino acid.

Milling of wheat increases the proportion of starch and sugars and lowers the proportion of other nutrients. Mineral content decreases with the refining process, and the contents of dietary fiber, protein, and fat also decrease significantly (**tables 12** and **13**). For example, the contents of potassium and magnesium, which are important growth (type II) nutrients, are reduced by two-thirds in white flour [93]; this is discussed in more detail in the section on Minerals, above. Refined flour contains no lignin and has much less insoluble fiber than whole-grain flour [200] (**table 12**). The extraction rate of whole-wheat flour is typically 85%, whereas white flour has an extraction rate of about 60%. In white flour, most of the fibers are lost.

TABLE 12. Macronutrients and energy in cereal staples (values/100 g)[a]

	Energy				Protein	Lipids			Carbohydrates		
Cereal	Total (kcal)	Protein (E%)	Fat (E%)	Carbohydrates (E%)	Total (g)	Total (g)	PUFA (g)	n-6:n-3 wt/wt ratio	Total (g)	Dietary fiber (g)[b]	Insoluble fiber (g)[c,d]
Wheat											
Flour, whole-meal (85% extraction)	341	11.9	6.0	82.1	10.7	2.4	1.1	14.6	74.1	11.6	1.0[d]
Flour, white (60% extraction)	354	10.8	4.0	85.2	9.6	1.6	0.7	14.6	76.0	3.7	—
Rice											
Brown, raw	368	9.7	7.1	83.2	9.0	2.9	1.0	37.7	76.6	2.4	—
White polished, raw	364	9.3	3.0	87.7	8.4	1.2	0.4	37.3	79.0	0.7	0.2[d]
White parboiled, raw	364	7.8	1.2	79.8	7.4	1.2	0.4	36.9	79.8	0.9	—
Maize											
Meal, whole-grain, white/yellow[e]	362[e]	8.7[e]	8.8[e]	82.5[e]	8.1[e]	3.6[e]	1.6[e]	—	76.9[e]	7.3[e]	—
Meal, degermed, white/yellow[e]	369[e]	8.1[e]	4.5[e]	87.4[e]	7.3[e]	1.8[e]	0.7[e]	—	79.2[e]	4.0[e]	—
Oats											
Rolled	366	13.7	15.3	71.0	13.2	6.5	2.7	29.9	68.2	10.1	—
Sorghum											
Whole-grain	355[d]	11.7[d]	8.6[d]	79.7[d]	10.4[d]	3.4[d]	1.4[e]	—	71.0	6.3[e]	2.0[d]
Flour	353[d]	11.3[d]	6.3[d]	82.4[d]	10.0[d]	2.5[d]	—	—	73.0	—	1.5[d]
Millet											
Pearl, whole-grain	363[d]	12.0[d]	12.3[d]	75.7[d]	11.0[d]	5.0[d]	2.1[e]	—	69.0	8.5[e]	2.0[d]
Pearl, flour	365[d]	9.8[d]	7.4[d]	82.8[d]	9.0[d]	3.0[d]	—	—	76.0	—	1.0[d]
Finger, whole-grain	336[d]	7.1[d]	4.0[d]	88.9[d]	6.0[d]	1.5[d]	—	—	75.0	—	3.0[d]
Finger, flour	332[d]	6.6[d]	2.2[d]	91.2[d]	5.5[d]	0.8[d]	—	—	76.0	—	2.4[d]

E%, energy percent; PUFA, polyunsaturated fatty acid

a. Source: National Food Institute (Denmark)[28], unless otherwise noted.

b. Dietary fibers are determined by different methods.

c. Insoluble fiber roughly is equivalent to crude fiber, whose definition is based on an outdated analysis method: the edible part of the plant that is insoluble in strong acids and alkalis.

d. Source: Platt [203]

e. Source: US Department of Agriculture [27].

TABLE 13. Energy and nutrient densities in cereal staples[a]

Cereal	Total energy (kcal/ 100 g)	Nutrient density/1,000 kcal							
		Folate (μg)	Vitamin B_1 (mg)	Calcium (mg)	Phosphorus (mg)	Iron (mg)	Zinc (mg)	Iodine (μg)	Phytate (mg)
Recommended nutrient density/1,000 kcal[b]	NA	220	0.6	600	600	9	13	200	NA
Wheat									
Flour, whole-meal (85% extraction)	341	147	1.1	88	918	9.7	7.6	7.9	890[c]
Flour, white (60% extraction)	354	51	0.5	48	331	3.3	2.3	5.4	190[c]
Rice									
Brown, raw	368	144	1.3	32	1,005	3.5	4.3	12.2	—
White polished, raw	364	85	0.2	145	357	3.3	4.7	6.0	130[c]
White parboiled, raw	363	50	1.7	357	471	3.3	4.7	6.1	
Maize									
Meal, whole-grain, white/ yellow[d]	362	69	1.1	16	666	9.5	5.0	—	900[c]
Meal, degermed, white/ yellow[d]	369	81	0.4	8	285	3.0	1.9	—	—
Oats									
Rolled	366	126	1.1	491	1,243	10.7	8.3	1.4	880[e]
Sorghum									
Whole-grain[f]	355	—	1.4	90	809[d]	13	—	—	1,080[e]
Flour[f]	353	—	1.1	56	—	11	—	—	—
Millet									
Pearl, whole-grain[f]	363	83	0.8	69	661	8.3	9.4	14	830[e]
Pearl, flour[f]	365	—	0.5	41	—	5.5	—	—	—
Finger, whole-grain[f]	336	—	0.9	1,042	—	15	—	—	—
Flour[f]	332	—	0.5	1,115	—	12	—	—	—

a. Source: National Food Institute (Denmark)[28] unless otherwise noted.
b. Values from Golden [4].
c. Source: Egli et al. [142].
d. Source: US Department of Agriculture [27].
e. Source: Egli et al. [150].
f. Source: Platt [203].

An extraction rate of about 80% is a prudent balance between not reducing the nutrient content too much and reducing the fiber content.

Rice

Rice is the main staple food of over half the world's population [201]. Rice proteins have a higher content of lysine than most other cereal proteins, and rice protein is considered to be of high quality, with one of the highest PDCAAS among cereals. However, rice has one of the lowest protein contents among cereals, and despite a relative high lysine content, the limiting amino acids are lysine and threonine [201, 202]. Brown rice (in which only the hull is removed) has higher energy content due to a higher fat content and also a higher vitamin B content, but it also has a higher content of fiber. The loss of vitamin B in milled rice can be partly prevented by parboiling [201, 202].

Parboiling is a process in which the whole grain is soaked, steamed, and dried. During soaking, the water-soluble nutrients become more evenly distributed throughout the whole grain and are hardly removed during dehulling. During drying, the outer coat of the grain is hardened by the heat so that when the grain is stored it is more resistant to insect invasion.

Rice is rarely ground to flour. However, it is often milled into a highly refined product, losing a high proportion of vitamins and other important nutrients in the process. The primary objective in rice milling is to remove the hull and the bran with minimum breakage of the endosperm. This is achieved by cleaning, shelling or dehulling, and milling. In brown rice, only the hull is removed. The traditional method of pounding rice in a wooden mortar and winnowing it results in the loss of about half of the outer layers and germ [196].

Maize

Maize, or corn, is used as a staple food mainly in the Americas and in Africa. The major nutritional component in maize is starch in the form of amylose and amylopectin. The maize kernel contains about the same amount of protein as other cereals, but with a lower content of lysine and tryptophan. The fat content is high, about 9% of the energy in whole-grain maize. Maize oil has a high content of PUFAs, mainly linoleic acid (24%), and thereby a high n-6/n-3 fatty acid ratio [204]. Whole-grain maize has a low content of niacin, even compared with wheat and rice. Furthermore, it is in a form with reduced availability [196]. In South America, maize is often treated with lime water, which makes niacin better available.

In the late 1930s, Cicely Williams made the first description of kwashiorkor and reported that it was associated with a maize diet [205]. However, since most of the children had a history of deficient breastfeeding and only received maize as supplementary food, it may not have been a characteristic of maize that caused kwashiorkor in that setting.

Milling of maize reduces the nutritional value, as in other cereals. The milling of maize yields a variety of products. There are two methods of milling maize: dry and wet milling [204]. Wet milling produces starch, syrups, and dextrose for use in the food industry. The most common process used in low-income countries is dry milling. In dry milling, the hull and germ are stripped from the endosperm and can be totally separated from the endosperm [206]. Degermed and dehulled maize has an extraction rate of 60%, which almost doubles the price compared with whole-meal flour. Traditional methods using stones or pestle and mortar are still common in many low-income countries. With these methods, the grains lose some of their outer coat but retain some of the lipid-rich outer layers. Because of the fat content, the products become rapidly rancid, and milling has to be done frequently [207].

Oats

Oats are grown mainly in cold areas and are not considered an important crop in the diets of most low-income countries. Oats have a high nutritional value. Oats have a higher protein content (13 g/100 g) than maize, rice, and wheat and also have a high lysine content and thereby a high PDCAAS. However, there is also a considerable quantity of phytic acid. The lipid concentration of oats is higher than that of other cereals, with a favorable ratio of unsaturated to saturated fatty acids compared with other cereals. Oats are appropriate for children with moderate malnutrition, but because of price and availability they are often not a realistic option.

Sorghum and millets

Sorghum and the several millet species are grasses with an ancient history of cultivation in Africa and Asia (**table 14**). They are relatively drought-resistant crops and are suitable for production under difficult agronomic conditions. Sorghum and millets for human consumption are mostly grown in Africa and India, although their production is declining as they are being replaced by maize and rice. Sorghum and millets are often grown for subsistence use and are therefore important crops for local food security in some arid and semiarid regions. Sorghum and millets are used in a range of traditional foods and beverages, such as thin and stiff porridges, unleavened flatbreads, and beverages.

There are white and colored varieties of sorghum and millet species. The colored varieties contain tannins and have some agronomic advantages because they are more resistant to bird and pest attacks, but the tannins have a negative impact on the nutritional value because of their antinutrient properties.

Millets are various species of small seeded grasses, of which the major species for human consumption are pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*). The nutritional quality, including

TABLE 14. Origins and common names of sorghum and millets[a]

Scientific name	Common names	Suggested origin
Sorghum bicolor	Sorghum, great millet, guinea corn, kafir corn, aura, mtama, jowar, cholam. kaoliang, milo, milo-maize	Northeast quadrant of Africa (Ethiopia-Sudan border)
Pennisetum glaucum	Pearl millet, cumbu, spiked millet, bajra, bulrush millet, candle millet, dark millet	Tropical West Africa
Eleusine coracana	Finger millet, African millet, koracan, ragi, wimbi, bulo, telebun	Uganda or neighboring region
Setaria italica	Foxtail millet, Italian millet, German millet, Hungarian millet, Siberian millet	Eastern Asia (China)
Panicum miliaceum	Proso millet, common millet, hog millet, broom-corn millet, Russian millet, brown corn	Central and eastern Asia
Panicum sumatrense	Little millet	Southeast Asia
Echinochloa crus-galli	Barnyard millet, sawa millet, Japanese barnyard millet	Japan
Paspalum scrobiculatum	Kodo millet	India

a. Source: FAO [208].

the protein and fat contents, varies with the species and varieties. Both sorghum and millet species in general have high fiber contents. The total dietary fiber content is reported as 17% to 20% in millets and 14% in sorghum [208].

Industrially and home-based processing of sorghum and millets includes mechanical milling to obtain dehulled, refined flour. Milling of sorghum removes 10% to 30% of the original weight. Traditional processing of sorghum and millets includes fermentation, soaking, and germination,which can contribute to improving the nutritional quality by reducing the contents of tannins and fibers.

Sprouts of germinated sorghum contain a cyanogenic glucoside that can be hydrolyzed to highly toxic cyanide (HCN) [209], and the fresh shoots and roots of germinated sorghum must therefore never be consumed.

Quinoa

Quinoa is grown as a crop primarily for its edible seed. It is a pseudo-cereal rather than a true cereal, as it is not a grass. Its leaves are also eaten as a vegetable. Quinoa originates from South America and is still mainly grown there [210]. Quinoa has a balanced content of essential amino acids and thus a high protein quality [211]. It is also a source of vitamin E, thiamine, iron, zinc, and magnesium [212, 213]. Quinoa has a coating of bitter-tasting saponins, which can be removed by soaking [214].

Teff

Teff is grown mainly in Ethiopia and Eritrea and to a lesser extent in India and Australia. The grain has a high content of several nutrients, including calcium, phosphorus, iron, copper, and thiamine. Teff also has a good amino acid composition and has lysine levels higher than those of wheat. In Ethiopia and Eritrea, teff is mainly used in enjera, a fermented thin, flat pancake, which is consumed mainly by adults. The high contents of important nutrients, combined with the advantages of fermentation (**table 11**) (see section on Fermentation, above), make enjera a potentially valuable food for malnourished children, but the tradition is to feed infants and young children porridge and pancakes made from unfermented teff. Teff is considerably more expensive than other cereals.

Conclusions and recommendations on cereals

- Cereals are important ingredients in diets for children with moderate malnutrition, as they provide easily available and low-cost energy, protein, and important nutrients.
- In choosing the best cereal types for treating children with moderate malnutrition, the contents of nutrients, fibers, and antinutrients, especially phytate, should be taken into consideration.
- A high extraction rate will reduce the contents of fibers and antinutrients, but also the contents of nutrients. Thus, the optimal extraction rate is a balance that differs according to the type of cereal and the target population
- White rice, wheat flour with a 85% extraction rate, and maize flour with a 60% extraction rate are prudent choices for feeding children with moderate malnutrition.

Legumes and pulses

Legumes are plants from the family Fabaceae or the fruits of these plants. Well-known legumes include peas, beans, and peanuts. The FAO has defined "pulses" as legumes harvested solely for the dry grain. This definition excludes green beans and green peas, which are considered vegetable crops. Crops that are grown mainly for oil extraction (oilseeds such as peanuts and soybeans) are also excluded. Legumes play an important role in the diets of people in Asia, India, South and Middle America, and to some extent in Africa.

Legumes have a high nutritional quality. The protein content is high, typically from 20 to 35 g/100 g, or a protein energy percentage of 20 to 30. The quality of the protein is not high because of a low content of methionine. The lysine content is high compared with cereals, and therefore legumes complement the low lysine content of cereals, resulting in a high PDCAAS in foods containing both cereals and legumes. The fat content is low, about 1% to 3%, with the exception of whole peanuts and soybean, which contain about 43 and 18 g of fat/100 g, respectively.

The total content of fiber is generally high, typically around 5 to 15 g/100 g dry weight, of which 4 to 5 g/100 g is insoluble fiber (**table 15**). The content of phytate is high in legumes, at the same level as in whole-grain cereals (**tables 13** and **16**). However, in cereals the phytate is located mainly in the outer layers and can be removed more easily during processing, which is not the case with legumes. Therefore, the phytate content is higher in legumes. An analysis of complementary foods from Indonesia found that legumes typically had phytate contents three to four times higher than those in cereals [215]. Colored legumes also have high levels of polyphenols.

Legumes often contain high amounts of indigestible oligosaccharides (stacchiose and rafinose) that are rapidly fermented in the colon and can cause undesired flatulence [216]. This gas production may play a role in the acceptability of legumes, including soybean products, as a major food source for humans [217–220].

Lentils

Lentil is a plant of the legume family with lens-shaped seeds. Lentils are used to make daal, a traditional dish with cooked lentils. Lentils can be white, yellow, red,

TABLE 15. Macronutrients and energy in starchy roots and legumes (values/100 g)[a]

Food	Energy				Total protein (g)	Lipids			Carbohydrate		
	Total (kcal)	Protein (E%)	Fat (E%)	Carbohydrates (E%)		Total (g)	PUFA (g)	n-6:n-3 wt/wt ratio	Total (g)	Dietary fiber (g)[b]	Insoluble fiber (g)[c]
Legumes											
Kidney bean	339	28.3	4.5	67.2	24.0	1.7	—	—	57.0	—	4.0[d]
Mung bean, raw, dry	312	27.0	3.3	69.7	24.2	1.3	—	—	62.6	15.0	4.6[d]
Brown bean, dry	314	21.8	5.2	73.0	18.9	2.0	—	—	63.4	17.8	—
Red lentil, raw, dry	361	29.5	7.1	63.4	27.3	2.9	1.1[e]	—	58.5	6.2	4.0[d]
Brown lentil, raw, dry	340	28.0	5.0	67.0	25.1	2.0	0.5[e]	—	60.1	11.2	4.0[d]
Soy flour, full fat	449	31.6	42.5	25.9	37.2	22.2	12.6	7.1	30.5	10.4	—
Soy flour, defatted	375	45.4	20.0	34.6	45.5	8.9	3.9	—	34.9	16.0	—
Peanut, dry	557	16.7	64.3	19.0	24.9	42.7	14.5	∞	28.4	7.7	3.0[d]
Starchy roots[e]											
Cassava, raw	120	10.0	2.9	87.1	3.1	0.4	0.1	1.9	26.9	2.5	1.0[d]
Sweet potato, raw	71	6.9	3.6	89.6	1.3	0.3	0.1	5.5	17.0	3.0	1.0[d]
Yam, raw	119	5.0	1.5	93.5	1.5	0.2	0.1	5.3	27.9	1.0	0.5[d]
Potato, raw	82	9.1	3.2	87.7	1.9	0.3	0.2	0.8	18.3	1.4	0.4[d]
Other[e]											
Plantain, raw	122	3.8	2.4	93.8	1.3	0.4	0.1	—	31.9	2.3	0.3[d]

E%, energy percent; PUFA, polyunsaturated fatty acid

a. Source: National Food Institute (Denmark) [28] unless otherwise noted.

b. Dietary fibers are determined by different methods

c. Insoluble fiber roughly is equivalent to crude fiber, whose definition is based on an outdated analysis method: the edible part of the plant that is insoluble in strong acids and alkalis.

d. Source: Platt [203].

e. Source: US Department of Agriculture [27].

green, brown, or black. Red, yellow, and white lentils have had their skins removed, i.e., they are decorticated. Some lentils contain a toxin that can cause latyrism, a neurological condition with paralysis [221]. The amount of toxin can be reduced by soaking, heating, and fermentation.

Beans

Beans are large seeds of plants of the family Fabaceae. There is a great variety of bean types that are produced in large parts of the world. Grams are a group of legumes that includes pigeon peas, chick peas, green grams, and mung beans [196].

The protein content of beans is between 20% and 30%. The PDCAAS is reasonably good, although their overall value is reduced by their lower digestibility [222]. Beans are generally very low in fat, containing about 2% to 5% of energy as fat, and the dietary contribution of beans to the intake of n-3 fatty acids, due to the content of α-linolenic acid, is generally minor [223]. Beans are an excellent source of folate. Even though beans have relatively high contents of both calcium and iron, they are not a very good iron source because of the low bioavailability of iron from legumes [224–227]. Beans provide a large amount of dietary fiber.

Beans contain several antinutrient factors, of which the most important are trypsin inhibitors, phytate, and lectins. The phytate content of beans is between 1% and 2%, which contributes to the poor bioavailability of minerals in beans [228, 229].

Soybean

Soybeans are an important crop, providing primarily high contents of oil and protein. Soybeans occur in various colors: black, brown, blue, green, and yellow. The oil and protein contents together account for about 60% of the weight of dry soybean flour (protein 37% and oil 22%) (**table 15**).

The protein content is of high quality. It contains all the essential amino acids. With the exception of the sulfur amino acids, cysteine and methionine, in which soybeans are deficient, other essential amino acids are present in sufficient quantities; noteworthy is the high amount of lysine, which distinguishes soybeans from other legumes and cereals [230, 231], and provides soy protein with a high PDCAAS. For this reason, soybeans are a good source of protein, especially for those living on a diet low in animal-source foods.

TABLE 16. Nutrient densities in starchy roots and legumes[a]

Food	Total energy (kcal/100 g)	Nutrient density/1,000 kcal						Phytate (mg/ 100 g)[b]	Phytate ratio (molar)[b]	
		Folates (µg)	Vitamin B_1 (mg)	Calcium (mg)	Phosphorus (mg)	Iron (mg)	Zinc (mg)		Phyt:Fe ratio	Phyt:Zn ratio
Recommended nutrient density/1,000 kcal[c]		220	0.6	600	600	9	13	—	—	< 15
Legumes										
Kidney bean[d]	339	—	1.5	325	—	23.6	—	—	—	—
Mung bean, raw, dry	312	1,041	1.2	282	1,266	24.7	8.v6	833[e]	15.2[e]	28.5[e]
Brown bean, dry	314	446	1.1	245	1,519	15.9	6.4	—	—	—
Red lentil, raw, dry	361	565[f]	1.4[f]	114	1,019	20.9[f]	10.8[f]	—	—	—
Brown lentil, raw, dry	340	1,409[f]	2.6[f]	206	1,097	22.2[f]	14.1[f]	115[g]	—	—
Soy flour, full fat	449	1,782	1.7	334	1,237	8.9	11.1	763[e]	11.3[e]	19.1[e]
Soy flour, defatted[e]	375	813	2.9	760	1,800	21.9	10.9	—	—	—
Peanut, dry	557	190	1.6	100	734	3.4	5.6	814[e]	10.6[e]	23.7[e]
Starchy roots										
Cassava, raw	120	183	1.9	758	583	30.0	2.1	—	—	—
Sweet potato, raw	71	199	1.0	638	397	12.8	2.8	—	—	—
Yam, raw	119	193	0.9	143	462	4.2	2.0	—	—	—
Potato, raw	82	441	0.7	86	673	12.7	3.7	—	—	—
Other										
Plantain, raw[e]	122	180	0.4	24.6	278.7	4.9	1.1	—	—	—

a. Source: National Food Institute (Denmark) [28], unless otherwise noted.
b, Phytate (mg/100 g) is based on the sum of IP5 and IP6.
c. Values from Golden [4].
d. Source: Platt [203].
e. Source: Chan et al. [215].
f. Source: US Department of Agriculture [27].
g. Source: Egli et al. [150].

The oil content is of high quality, as soy oil contains a high proportion of unsaturated fatty acids, with a high content of the n-3 fatty acid α-linolenic acid and thereby a favorable n-6/n-3 PUFA ratio of about 7. The fatty acid content of soybeans is discussed in more detail in the section on Oils and Fats, below.

On average, dry soybeans contain about 35% carbohydrates. The insoluble carbohydrates in soybeans include cellulose, hemicellulose, pectin, and a trace amount of starch. Soybeans contain both water-soluble and fat-soluble vitamins. The water-soluble vitamins are mainly thiamine, riboflavin, niacin, pantothenic acid, and folic acid. Soybeans also contain vitamin C, but the amount is negligible in mature soybeans, although it is present in measurable amounts in both immature and germinated seeds [231]. The fat-soluble vitamins in soybeans are vitamins A and E, with essentially no vitamins D and K. Vitamin A is present mainly as the provitamin β-carotene, and the content is negligible in mature seeds.

As in most legumes, there is an abundance of potassium but not of sodium, and soybeans are a very good source of phosphorus, although a significant proportion of it is present as phytic acid phosphorus, which has only partial biological availability. Soybeans are also a good source of calcium and magnesium, but they are poor in iron. The amounts of zinc, iron, and iodine are minimal [231]. Soybeans contain antinutritional factors, of which the most important are protease inhibitors, lectin, and phytates.

A range of soy products are used for vulnerable and undernourished populations. The most common products are whole soybeans or grits, full-fat soy flour, and defatted soy flour [232]. In corn–soy blend, nondehulled and dehulled soybeans and defatted and toasted soy flour have been used [152]. Other more refined products are soy protein concentrates and soy protein isolates, the latter used in infant formula. The difference between defatted soy flour, soy concentrates, and soy isolates is not only the carbohydrate content, which is 32%, 21%, and 3% respectively, but also the content of fiber and antinutrients which is reduced, although important quantities are left even in soy isolates [127, 218, 233, 234].

In conclusion, soybeans have exceptionally high contents of both protein and fat. The quality of protein is high, with a balanced amino acid composition and thereby a high PDCAAS, and the quality of fat is also good, with a relatively high contribution from n-3 PUFAs and thus a favorable n-6/n-3 fatty acid ratio. On the other hand, soybeans also contain high levels of antinutrients, especially phytate, and high levels of phytoestrogens (see section on Phytoestrogens, above). There is a lack of studies on the potential negative effects of the antinutrients in soybeans in malnourished infants and young children. Studies of growth in weanling pigs have shown that growth is better on a milk-based diet than a corn–soy diet [23]. But whether that is due to beneficial effects of milk or antinutritional effects of the soy and corn is not known. There is an urgent need to perform studies of the effects of different preparations of soybeans with different contents of antinutrients on growth.

Peanuts

The peanut is also known as groundnut and is one of the most nutritious seeds and one of the world's most popular legumes or pulses. In Africa peanuts are prepared as fresh boiled peanuts or roasted. They may also be ground or milled, and ground peanut is often available at markets to prepare peanut sauce [196, 235].

With more than 40% fat, peanuts contain more fat than other legumes. The protein content is about 25%, but peanuts are deficient in lysine and methionine. The amount of carbohydrate is relatively low at about 28%. Peanuts have little or no carotene but are a good source of vitamin E, niacin, and folate [236]. The fatty acid composition is discussed in the section on Oils and Fats, below. Peanuts have higher levels of phytate than most other legumes (**tables 7** and **15**) and also contain α-galactosides.

Conclusions and recommendations on legumes and pulses

» Legumes and pulses are important foods for children with moderate malnutrition because they have a high content of protein with an amino acid composition that complements the amino acid profile of cereals.
» The content of fibers and antinutrients is high, and optimal processing to reduce the amounts is important.
» Soybeans are used extensively as a commodity with a high protein content and quality at a reasonable price. However, the contents of fibers and phytate differ considerably between different soybean products.
» Soybeans have a high content of fat, with a high content of PUFAs and an optimal n-6/n-3 balance.

Research recommendations

» There is a need to examine the potential growth-inhibiting effect of different soy preparations with different degrees of processing.

Roots

Roots provide primarily energy in the human diet in the form of carbohydrates. In low-income countries, the main nutritional value of roots is their potential ability to provide one of the cheapest sources of energy in the form of carbohydrates. Both protein and fat contents are very low.

Cassava

Cassava is a starchy root that is an essential part of the diet of more than half a billion people. It is originally from South America but is now grown in many places. Cassava is also known as manioc or tapioca. It is drought resistant, needs little attention, and gives a high yield. Both the tubers and the leaves are used as food sources. The tubers are an important staple food in many low-income countries of Africa, South and Central America, India, and Southeast Asia, providing a cheap carbohydrate source. About 90% of the energy content in cassava comes from carbohydrates, mainly starch. Cassava is deficient in protein, with only about 3% of the energy coming from protein and only 1% from fat. Cassava species contain varying amounts of toxic cyanogenic glycoside, which can cause the paralytic disease konzo and can interfere with the function of the thyroid gland and cause goiter [177, 237]. The cyanide content can be reduced by soaking or boiling, but fermentation is more effective. Cassava leaves have high contents of carotene, vitamin C, iron, and calcium. The leaves contain more protein than the tubers, but they lack methionine [196, 238].

Potatoes and sweet potatoes

Potatoes belong to the nightshade family (Solanaceae) and have a high protein content (9 E%) with a high protein quality (PDCAAS) (**table 2**), higher than that of any of the cereals or other roots. The content of fibers is low, and the contents of vitamin C and potassium are high. During the last decade, there has been a marked increase in potato production in many developing countries. Because of the potential role of potato production in food security and poverty reduction, the United Nations and the FAO declared 2008 as the year of the potato (www.potato2008.org). Sweet potatoes are starchy roots belonging to the bindweed family (Convolvulaceae) that are widely grown as staple foods in parts of Africa and Asia. Sweet potatoes have the same energy content as potatoes but a lower protein content, equivalent to about 7 E%. The yellow forms of sweet potato (orange-fleshed sweet potatoes) contain higher amounts of provitamin A carotenoids than the white forms and have been promoted as a dietary supplement to improve vitamin A status in vitamin A–deficient children [239, 240].

Plantain

Plantain is a form of banana and thus a fruit, not a root, but it is often classified with starchy roots, as it has a nutritional composition close to that of starchy roots. Plantains contain more starch than bananas and are either boiled or fried or made into a flour after sun-drying [196].

Conclusions and recommendations on roots

» Roots are typically cheap sources of energy, but the protein and fat contents are low and they are therefore not optimal as foods for children with moderate malnutrition.

» Potatoes are a valuable food with a high content and quality of protein and a low content of fibers and phytate.

Vegetables

A vegetable is not botanically defined, as it may be any edible part of a plant, such as the root, stem, leaves, or fruit. Many vegetables, such as carrots, onions, tomatoes, pumpkins, okra, aubergines, and green peas, can be valuable ingredients in diets for children with moderate malnutrition. In addition to the energy and nutrients they provide, they bring taste, color, and variability to the diet. Although vegetables typically shrink when cooked, they are often not very energy dense and can contribute to the bulkiness of the meal. They may also contain considerable amounts of fiber, which is part of the bulk problem. Many vegetables contain important amounts of micronutrients, especially provitamin A, vitamin C, and iron. Although the bioavailability of minerals in vegetables can be low because of antinutrients, the high amounts of vitamin C may improve the mineral bioavailability of the whole meal. Vegetables such as green leaves and fruits can be grown in home gardens or gathered from fields or bushes at the village level. Some vegetables, such as tomatoes, can be sun-dried and used later in cooked meals. Vegetables may therefore be affordable and valuable ingredients in diets for children with moderate malnutrition.

Conclusions and recommendations on vegetables

» Many vegetables are affordable and nutritionally valuable ingredients in diets for children with moderate malnutrition.

Green leafy vegetables

Dark-green leafy vegetables such as kale, spinach, and leaves of cassava, pumpkin, amaranth, and taro are widely available and are consumed as part of the normal diet in many populations. Green leafy vegetables are rich sources of provitamin A, vitamin C, iron, and calcium (**tables 17** and **18**). They are almost always cooked before consumption, which causes them to shrink in volume and become more nutrient dense. However, cooking may affect the bioavailability and activity of the nutrients. Cooking destroys 50% to 80% of vitamin C but improves the bioavailability of β-carotene [98].

TABLE 17. Macronutrients and energy in selected green, leafy vegetables (values/100 g of raw, edible portion)[a]

Vegetable	Energy (kcal)	Protein (g)	Lipid (g)	Protein (E%)	Lipid (E%)
Pumpkin leaves	19	3.15	0.40	68	19
Kale	50	3.30	0.70	27	13
Amaranth leaves	23	2.46	0.33	43	13
Spinach	23	2.86	0.39	50	15
Taro leaves	42	4.98	0.74	48	16

E%, energy percent

a. Source: US Department of Agriculture [27].

TABLE 18. Nutrient densities per 1000 kcal in selected green, leafy vegetables[a]

Vegetable	Vitamin A (μg RAE)	Vitamin B_1 (mg)	Vitamin B_{12} (μg)	Vitamin C (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	Phosphorus (mg)
Recommended density/1,000 kcal[b]	960	0.6	1.0	75	600	9	13	600
Pumpkin leaves	5,137	0.5	<0.01	583	2,066	117.6	10.6	5,508
Kale	15,469	0.2	<0.01	2,414	2,716	34.2	8.9	1,126
Amaranth leaves	6,298	0.1	<0.01	1,868	9,274	100.1	38.8	2,157
Spinach	20,230	0.3	<0.01	1,212	4,270	116.9	22.9	2,114
Taro leaves	5,697	0.5	<0.01	1,229	2,529	53.2	9.7	1,418

RAE, retinol activity equivalents

a. Source: US Department of Agriculture [27].

b. Values from Golden [4].

Even though the conversion of provitamin A carotenoids is less effective than previously believed [98], green leafy vegetables consumed daily are still a valuable source of vitamin A, even with a low intake of dietary fat [241]. Since green leafy vegetables can be grown at home at low cost, they may serve as a reasonable alternative to vitamin A–rich animal-source foods. Home gardening of green leafy vegetables combined with nutrition education in rural South Africa improved the vitamin A status of 2- to 5-year-old children compared with children in a control village [242].

The iron content of most green leafy vegetables is relatively high, although the bioavailability of iron is compromised by a high content of tannins and oxalates [243].

Overall, consumption of green leafy vegetables improves the nutrient quality of cereal-based diets, although the bioavailability of vitamin A as well as that of iron is low.

Moringa leaves

The tropical drought-resistant tree *Moringa oleifera* is native to India but has been introduced to Africa and South America. The leaves are consumed raw, cooked like other green leaves, or as a dried, concentrated powder. Moringa is suitable for home gardening, as it is easy to grow and its fresh leaves can be harvested continuously. It has been claimed to have unusually high contents of calcium, iron, vitamin A [244], and high-quality protein and low contents of antinutrients such as tannins and oxalates [245]. Moringa leaves have therefore been promoted as a potential low-cost, high-quality food. Published data on the nutrient content of moringa leaves are, however, inconsistent [244, 246, 247], probably reflecting different pre- and postharvest procedures, varieties, leaf age, etc. There is limited information on the bioavailability of nutrients from moringa leaves, although they were effective in improving vitamin A status in depleted rats [248]. Systematic nutrient analyses and human intervention trials assessing the effects of consumption of moringa leaves are needed before the potential effects of the moringa tree can be estimated.

Conclusions and recommendations on green leafy vegetables

» Green leafy vegetables contain iron and provitamin A and can be valuable ingredients in diets for moderately malnourished children.

Research recommendations

» Leaves from the moringa tree may be rich in minerals and provitamin A, but the actual contents and bioavailabilities need to be assessed. The value for children with moderate malnutrition should be examined further.

Fruits

Most fruits contain readily available energy in the form of simple sugars, mainly fructose. Those with orange- or yellow-colored flesh are rich in provitamin A (**tables 19** and **20**). Fresh fruit is an excellent source of vitamin C and should be consumed with plant-based meals to enhance absorption of iron. In addition, the bioavailability of provitamin A is relatively high from fresh fruits [96]. Most children like the natural sweetness of fruits, so the addition of fresh fruit to a meal may increase its perceived palatability and thus increase the intake of the whole meal. Avocado has an exceptionally high content of fat, about 15 g/100 g, with about two-thirds being monounsaturated fat. The energy density is therefore high, more than 1.6 kcal/g. Therefore, if available and affordable, avocadoes are valuable in the diet of children with moderate malnutrition. Banana is also a high-energy food, with an energy density around 0.9 kcal/g. Ripe bananas have a high sugar content and thus provide an easily available energy supply. Unripe bananas have a high fiber content and are thus unsuitable for children with moderate malnutrition.

TABLE 19. Macronutrients and energy in selected fruits (values/100 g raw, edible portion)[a]

Fruit	Energy (kcal)	Protein (g)	Lipid (g)	Protein (E%)	Lipid (E%)
Apricot	48	1.0	0.0	8	0
Avocado	167	2.0	15.4	5	84
Banana	89	1.1	0.3	5	3
Fig	74	0.8	0.3	4	4
Guava	68	2.6	1.0	15	13
Orange	47	0.9	0.1	8	2
Mango	65	0.5	0.3	3	4
Passion fruit	97	2.2	0.7	9	7
Pineapple	50	0.5	0.1	4	2

a. Source: US Department of Agriculture [27]

TABLE 20. Nutrient densities per 1000 kcal in selected fresh fruits[a]

Fruit	Vitamin A (µg RAE)	Vitamin B_1 (mg)	Vitamin B_{12} (µg)	Vitamin C (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	Phosphorus (mg)
Recommended nutrient density/1,000 kcal[b]	960	0.60	1.0	75	600	9	13	600
Apricot	2,000	0.63	<0.01	208	271	8.1	4.2	479
Avocado	42	0.45	<0.01	53	78	3.7	4.1	323
Banana	34	0.35	0.34	98	56	2.9	1.7	247
Fig	95	0.81	<0.01	27	473	5.0	2.0	189
Guava	456	0.99	<0.01	3,357	265	3.8	3.4	588
Orange	234	1.85	0.85	1,132	851	2.1	1.5	298
Mango	585	0.89	<0.01	426	154	2.0	0.6	169
Passion fruit	660	0.00	<0.01	309	124	17	1.0	701
Pineapple	60	1.58	0.40	956	260	5.8	2.4	160

RAE, retinol activity equivalent

a. Source: US Department of Agriculture [27].

b. Values from Golden [4].

Conclusions and recommendations on fruits

- Most fruits are good sources of vitamin C and should be consumed raw with plant-based meals to enhance iron absorption.
- Yellow- and orange-fleshed fruits are good sources of provitamin A.
- Fruits add sweetness and color to a meal, factors that will improve perceived palatability and often increase dietary intake among children.
- The intake of fruits should be promoted, as they currently have low status in many settings.

Algae

Algae are aquatic photosynthetic organisms that are classified into macro- and microalgae based on their size. The macroalgae are a group of larger aquatic plants to which the common name seaweeds is applied. The microalgae (phytoplankton, Cyanophyceae) are unicellular microscopic aquatic plants. Many species are edible. Some algae, mainly the seaweed *Porphyra* sp. (nori) and the cyanobacterium *Spirulina* sp., contain large amounts of vitamin B_{12} [249]. However, the majority of algal vitamin B_{12} appears to be widely nonbioavailable in humans [249], and therefore algae cannot be recommended as an alternative to animal-source foods as a vitamin B_{12} source.

Many algal species contain essential amino acids (histidine, leucine, isoleucine, and valine), and thus they represent a potential reservoir of protein appropriate for human consumption [250]. However, the algal protein is not readily available for humans, as algae are surrounded by an indigestible cellulose wall.

Seaweeds

Consumption of seaweeds is rarely seen as part of the food culture outside East Asia, and its acceptance may be limited in other settings. However, several seaweeds have high contents of iron, calcium, and iodine in particular [250] (**table 21**). Iodine and calcium in particular are of potential nutritional importance, whereas the bioavailability of iron is compromised by a high content of polyphenols.

In addition, seaweeds have a high content of soluble

TABLE 21. Mineral contents of seaweeds (values/100 g wet weight)[a]

Scientific name	Common name	Calcium (mg)	Iron (mg)	Iodine (mg)	Zinc (mg)
Ascophyllum nodosum	Egg wrack	575	15	18	—
Laminaria digitata	Kombu	365	46	70	1.6
Himanthalia elongata	Sea spaghetti	30	5	11	1.7
Undaria pinnatifida	Wakame	112	4	4	0.3
Porphyra umbilicalis	Nori	34	5	1	0.7
Palmaria palmata	Dulse	149	13	10	0.3
Chondrus crispus	Irish moss	374	7	6	—
Ulva spp	Sea lettuce	325	15	2	0.9
Enteromorpha spp	Sea grass	104	22	98	1.2

a. Source: MacArtain et al. [250].

fibers [250, 251]. A high content of antioxidants may be an adaptation to sunlight exposure in their natural habitat.

Microalgae

Microalgae were once considered a source of high-quality protein that might meet the protein needs of the growing world population [252]. Algal proteins are of high quality. However, the cellulose cell wall of algae presents a major constraint, as it cannot be digested by humans. Therefore, even microalgae need to be preprocessed, resulting in high production costs, in order to make the nutrients available for human digestive enzymes [252].

Although the algae appear to represent nutritious vegetable food, their use will probably be limited by their sensory characteristics (fishy taste and smell and green, brown, or red color) in populations where they are not part of the habitual diet [252]. Food preferences are conservative in many low-income countries, where the protein quality of the diet is generally low. Unknown food ingredients are not easily accepted, particularly in disadvantaged populations and in crisis situations. However, in East Asia or in coastal regions where algae are accepted, they should not be neglected, as they can provide important nutrients.

Spirulina

Spirulina belongs to the cyanobacteria. Unlike the true microalgae, *Spirulina* does not have cellulose walls, and therefore protein and other nutrients from *Spirulina* are more bioavailable than those from yeasts and unicellular algae [253]. Although the nutritional interest of other microorganisms has faded due to problems of digestibility, the cyanobacterium *Spirulina* may offer simple production of a high-quality nutritional supplement.

The protein quality of *Spirulina* is high, and it is reported to be rich in highly available iron, calcium, potassium, and phosphorus [254]. *Spirulina platensis* has a high content of essential n-6 PUFAs, linoleic acid (C18:2 n-6), and γ-linolenic acid (C 18:3 n-6). The total lipid content is around 6%, of which around 40% is PUFA [255, 256]. With a total energy content of around 340 kcal/100 g, the fat contributes 16 E%.

Spirulina grows naturally in some alkali lakes of Africa and can be produced in tanks appropriate for small-scale industry. However, when produced in ponds or basins it tends to accumulate heavy metals, so that water quality is very important. Alkaline production reduces the risk of contamination or overgrowth of most other microorganisms, as they cannot survive the high pH caused by *Spirulina*.

Spirulina (10 g daily) was used in an 8-week nutritional rehabilitation study of undernourished children in Burkina Faso [257]. Improved weight gain was reported with *Spirulina* as compared with traditional millet meals, particularly for HIV-negative children. Hemoglobin also improved with *Spirulina* supplementation. However, the randomization procedure was poorly described in this study. In another, larger study by the same group, *Spirulina* and misola (millet, soy, peanuts, and sugar) were compared with a two-by-two factorial design for nutritional rehabilitation of severely and moderately underweight children aged 6 to 60 months [256]. Unfortunately, the children receiving the control diet were chosen from those families who refused to be part of the trial. However, it appeared that a combination of *Spirulina* and misola was superior to *Spirulina* or misola alone, and that *Spirulina* or misola alone was superior to the control diet (of unknown composition). In conclusion, although the evidence is sparse, it seems that *Spirulina* deserves attention as a potential natural dietary supplement for use in the nutritional rehabilitation of moderately malnourished children.

Conclusions and recommendations on algae

- » Seaweeds are rich in iron, calcium, iodine, and a variety of antioxidants and contain several essential amino acids.
- » Seaweeds are traditionally used in East Asian food culture, but due to their sensory characteristics seaweeds may be difficult to introduce into other food cultures.
- » In East Asia and in coastal regions where seaweeds are accepted, they could be promoted as a nutritious component of diets for children with moderate malnutrition.
- » Microalgae may be good sources of micronutrients and high-quality protein, but availability might be low due to the cellulose content.
- » *Spirulina*, a cyanobacterium, seems to have protein and micronutrients with a better bioavailability and has a high content of n-6 PUFAs.

Research recommendations

- » Some studies suggest that *Spirulina* could have a role in treating children with moderate malnutrition, but this should be investigated further.

Animal-source foods

Animal products, such as meat, fish, eggs, and dairy products, are energy dense, excellent sources of high-quality and readily digested protein and micronutrients, and they contain virtually no antinutrients. The most important micronutrients in animal products are iron, zinc, calcium, riboflavin, vitamin A, and vitamin B_{12}. It has been concluded that “relatively small amounts of these foods, added to a vegetarian diet, can substantially increase nutrient adequacy” [258].

A number of studies have examined the role of animal-source foods in growth, mental development, morbidity, anemia, and immune function [258–264].

The beneficial role of animal-source foods (meat and milk) in the diets of 18- to 30-month-old children was investigated in the Nutrition Collaborative Research Support Program, conducted from 1983 to 1987 in rural areas of Egypt, Kenya, and Mexico. The estimated intakes of protein from animal sources were 13.5 g/day (11.1 g/1,000 kcal), 3.8 g/day (4.5 g/1,000 kcal), and 8.6 g/day (8.8 g/1,000 kcal), respectively, corresponding to 46%, 19%, and 37% of the recommended protein density of 24 g/1,000 kcal [4]. Positive associations were found between intake of animal-source foods and growth in weight and length, after controlling for socioeconomic factors [265]. Similarly, intake of animal-source foods was associated with linear growth in 12- to 15-month-old children in Peru [266], especially in those with a low intake of complementary foods. In Mexico, consumption of foods of animal origin was positively associated with body size in stunted children at 30 months and with growth rates from 18 to 30 months [267]. The iron, zinc, and vitamin B_{12} contents of animal-source foods, in addition to high protein quality, may have contributed to these findings [261, 268].

In an intervention study in Kenya, 12 schools with 544 children enrolled in class 1 were randomly assigned to meat (60 to 85 g/day), milk (200 to 250 mL/day), energy (isocaloric with the milk and meat, 240 to 300 mL/day), or no food supplement for a 2-year period [264, 269]. Children receiving meat had a greater increase in arm muscle area than children in the milk and energy groups, who had greater increases than children in the control group. The effect of milk on arm muscle area was not significantly greater than that of energy supplementation. There were no main effects of any of the supplements on linear growth. However, among children with low height-for-age z-scores at baseline, those receiving milk gained more height than children in the other groups [264]. Height gain during the intervention period was positively predicted by intakes of energy from animal-source foods, both milk and meat [263].

Other studies, from both industrialized and from developing countries, have suggested that milk has a specific stimulating effect on linear growth [270]. Observational and intervention studies from industrialized countries suggest that intake of cow's milk stimulates insulin-like growth factor 1 (IGF-1) secretion, which has a direct effect on linear growth [271, 272]. Equivalent amounts of protein in meat did not have an effect on IGF-1 levels [272].

Many studies have shown an impact of childhood malnutrition on cognitive function, physical activity, and school attendance and performance. Positive associations have been found between intake of animal-source foods and cognitive performance and verbalization in toddlers [273, 274], and school-age children receiving meat had better verbal and performance test results, were more attentive to classroom work, and showed leadership behavior [275, 276].

An overview of the characteristics of animal foods that are likely to cause the beneficial effects seen after intake of animal-source foods is given in **table 22**.

Milk

Cow's milk

Cow's milk is a good source of many nutrients and has a high content of high-quality protein, containing all essential amino acids. The PDCAAS is typically 120%, depending on the exact amino acid distribution, with tryptophan as the limiting amino acid. Mature bovine milk contains about 3.2% to 3.5% protein by weight, equivalent to about 20% of the energy. The main protein fractions of bovine milk are casein and whey, which account for approximately 80% and 20% of the protein, respectively. Whole cow's milk provides a good supply of energy (266 kJ/100 g), with 45% coming from fat, whereas skimmed milk provides only 151 kJ/100 g. Cow's milk also contains high levels of important nutrients, such as calcium, available phosphorus and magnesium, and several B vitamins and bioactive factors and proteins that may have growth-promoting abilities (see Bioactive Substances: Milk Peptides, above). However, cow's milk is a poor source of iron because of low iron content and poor bioavailability.

Because of its stimulating effect on linear growth, milk may have an important role in the prevention and treatment of stunting, especially during the first 2 years of life. However, it is also important in the treatment of moderate wasting, as a high-quality protein source with high levels of micronutrients and no antinutrients is likely to be important for lean body mass accretion.

The successful treatment of severely malnourished children is based on products with either 100% (F100) or about 50% (RUTFs) of the protein coming from milk. Milk should also be considered a key ingredient in the foods used for treatment of children with

TABLE 22. Characteristics of animal foods compared with plant foods to which the beneficial effects can be attributed

Higher content of micronutrients important for growth and cognitive development (e.g., zinc, iron, and vitamin B_{12})
Higher protein content and protein quality
No antinutrients
High energy density
High fat content
Higher content of n-3 PUFA

PUFA, polyunsaturated fatty acid

moderate malnutrition. There is no firm evidence to determine the minimum amount of milk that would have an impact in treatment of children with moderate malnutrition. Based on the available data of the effects of interventions with animal foods, it seems likely that a diet with 25 to 33% of the protein coming from milk would have a significant effect. However, there is need for studies to determine the minimum amount of milk that will have a significant effect. The amounts of milk equal to 25% to 33% of the recommended protein intake for children with moderate malnutrition (24 to 26 g/1,000 kcal [4]) are about 200 to 250 mL of liquid milk or 15 to 20 g of milk powder or whey protein powder (skimmed-milk powder or whey protein concentrate 34%) per 1,000 kcal.

Milk products

There are many different types of cow's milk products available, and in the following section the benefits and problems of using the different types of milk products in the treatment of children with moderate malnutrition will be discussed.

Liquid milk, i.e., either raw, pasteurized, or ultra-high-temperature (UHT)-treated milk, is suitable to give to children with moderate malnutrition. It should preferably be whole milk to provide a suitable balance between protein and fat intake. Skimmed milk or milk with a reduced fat content (< 2%) should not be given unless it is balanced with a fat intake that reaches the recommended level. Milk with reduced fat content also has a high renal solute load in relation to the energy content. A problem with pasteurized or UHT-treated milk is the high price. In soured and fermented milks such as yogurt, a *Lactobacillus* culture converts nearly all the lactose into lactic acid and a curd is formed. Apart from that, the nutritional content of soured milk is almost the same as that of the fresh milk from which it is made. Fermented milk or yogurt has many advantages. It keeps better, and the risk of growth of pathogenic bacteria is reduced. The content of lactic acid bacteria can have probiotic effects, for example through an influence on the gastrointestinal immune system, and may reduce the risk of diarrhea. Furthermore, the low pH will improve absorption of iron, and the reduction in lactose content during fermentation will reduce the effects of lactose intolerance, if present.

Powdered milk is often cheaper and more easily available than liquid milk. The most important problem with the use of powdered milk is the risk that the powder will be mixed with contaminated water when it is made into liquid milk. Since milk is a good growth medium, pathogens will easily multiply and can cause severe diarrhea. If milk powder is used for liquid milk, it should be mixed with boiled water and used within 1 to 2 hours to avoid contamination and bacterial proliferation. This problem of contamination is the main reason that many UN organizations [277] and international NGOs [278] have a policy of never distributing powdered milk as a take-home commodity. Another reason for not distributing powdered milk is that liquid milk in some situations may be perceived to be an infant formula and thereby have a negative effect on breastfeeding. The most common types of powdered milk available in areas with high levels of moderate malnutrition are whole-milk powder, which is often widely available in tins in local shops, and skimmed-milk powder, which is typically only available in large quantities (e.g., bags of 25 kg) for producers of food, UN organizations, and NGOs. Because of its high fat content, the shelf-life of whole-milk powder is limited to a year or less, depending on how it is packaged, whereas skimmed-milk powder can keep for several years if it is not fortified with vitamin A. Whole-milk powder can be used for liquid milk if food safety precautions are followed. Skimmed-milk powder should be used only as an ingredient in other foods, such as blended foods, and should not be used for making liquid skimmed milk. If skimmed-milk powder is used to make a drink without replacing the fat, the drink will be unsuited for infants and young children for the same reasons as skimmed milk. The relative contents of protein and minerals, and thus the renal solute load, will be too high if the fat is removed. This can be harmful, especially for infants and the youngest children [279].

"*Filled milk*" is a powdered product based on skimmed milk and vegetable oil that is sold in some low-income countries. Typically it is sold in small sachets sufficient for one glass of milk. The main advantage is that it is cheaper than whole-milk powder. The replacement of milk fat by vegetable oil could be beneficial from a nutritional point of view, depending on which vegetable oil is added.

Whey powder (13% protein) or whey protein concentrate (whey protein concentrate with 34% or 80% protein) is made from the liquid part of milk that remains after casein has coagulated in cheese production. It is often not easily available locally, but it can be used in programs in the preparation of special foods or blends for malnourished children, for example. Since it is a product left after cheese production, it is typically 20% to 30% cheaper than skimmed-milk powder per unit protein, which is an important aspect in the treatment of children with moderate malnutrition. Whey has a high content of both lactose and minerals. In whey powder (13% protein), the lactose content is about 70%. Whey contains many peptides and proteins with potential beneficial effects on the immune system and muscle synthesis, but this needs to be confirmed in studies of children with moderate malnutrition [23]. Because whey is a surplus product, it has been used extensively in feeding of weanling pigs. It is well documented that the growth of young weanling pigs is better on a whey-based diet than on a diet based on cereals and legumes [23]. There are not sufficient studies to evaluate whether the effect of whey is different from the effect of skimmed-milk powder, as the pig studies have focused on whey because it was cheaper.

Evaporated milks are normally full-cream milks with some water removed, although sometimes the milk fat is replaced with vegetable oil. Condensed milks are evaporated milks that may be made from whole milk or from milk from which the fat has been removed. They have a high concentration of sugar (about 45% by weight), which reduces the relative concentrations of protein and other nutrients and makes the milk unsuitable for use as a drink for infants and young children (see Sugar, below). Some evaporated and condensed milk is fortified with vitamins A and D. Both types of milk are sold in tins, are expensive, and should not be used as a drink. However, they can be mixed into porridge and other foods.

In *hard cheeses*, most of the whey is removed from the casein curd during processing. Therefore cheese has a low content of lactose and of all water-soluble vitamins, as they are removed with the whey. If made from whole milk, these cheeses contain vitamin A, a little vitamin D, and most of the original calcium. Cheese is expensive and therefore is not a relevant food for children with moderate malnutrition.

Milk from other domestic animals

Most of the animal milk consumed by humans is from cattle. The second highest amount is from buffalo. Buffalo milk is more concentrated than cow's milk, with higher energy, protein, and fat contents. Milk from many other domesticated animals is used for drinks or foods. **Table 23** shows the composition of milk from domesticated animals [280]. A general pattern is that some milks are more concentrated than others, with higher contents of energy, protein, and fat. This should be taken into account when calculating the amount to be given to children with moderate malnutrition. Some vitamin A and a little vitamin D is present in all milk fats. Some milk, such as goat's milk, has little or no folate compared with other milks. The concentration and availability of iron in all milks are low.

Conclusions and recommendations on milk

- » Liquid milk and milk powder are good sources of high-quality protein and micronutrients important for growth.
- » The minimum amount of milk protein needed to improve growth in children with moderate malnutrition is not known, but a milk content providing 25% to 33% of the protein requirement is likely to have a positive effect on weight gain and linear growth. However, studies should be conducted to determine the amount that is cost-effective.
- » 200 to 250 mL of milk or 15 to 20 g of milk powder or whey protein powder (skimmed-milk powder or whey protein concentrate 34%) per 1,000 kcal will provide 25% to 33% of the recommended protein intake (24 to 26 g/1,000 kcal).
- » Milk is likely to be more effective than meat in treating moderate stunting, as milk has a special effect on linear growth through stimulation of IGF-1 production.
- » Powdered milk with reduced milk fat, such as skimmed-milk powder or whey protein, should never be used for preparing liquid milk, because of the high protein content and risk of infection if mixed with contaminated water, but it can be mixed with blended foods or other foods that are cooked

TABLE 23. Composition of milk from domestic animals, compared with human milk[a]

Species	Energy (kcal/100 mL)	Protein (g/100 mL)	Lactose (g/100 mL)	Fat (g/100 mL)
Cow (*Bos taurus*)	61	3.2	4.6	3.7
Cow (*Bos indicus*)[b]	70	3.2	4.9	4.7
Yak	94	5.8	4.9	6.5
Musk ox	81	5.3	4.1	5.4
Water buffalo	88	4.3	4.9	6.5
Sheep	94	4.1	5.0	7.3
Goat	61	2.9	4.7	3.8
Ass	37	1.4	6.1	0.6
Horse	47	1.9	6.9	1.3
Camel	51	4.3	—	4.3
Dromedary	70	3.6	5.0	4.5
Llama	60	2.5	4.7	3.9
Human milk	78	1.0	7.5	4.2

a. Source: Jensen [280].
b. Zebu or humped cattle.

or heated.

- Whey contains peptides and proteins that have been suggested to have positive effects compared with skimmed-milk powder, but these effects have not been documented in children with moderate malnutrition.
- The effects of using whey instead of skimmed-milk powder in the treatment of children with moderate malnutrition should be tested in intervention trials, both because whey protein concentrate is cheaper than skimmed-milk powder and because of the potential beneficial effects of whey.
- Whole-milk powder should be used as a drink for children with moderate malnutrition only if it is prepared under strictly controlled and hygienic conditions.
- If milk is the only animal-source food given, sufficient iron should be provided in the diet.
- Fermented milk products should be promoted, as they have advantages over other milk products.

Research recommendations

- Research is needed to determine the amount of milk protein that has optimal cost-effectiveness in promoting growth.
- Research is needed to determine if there are any advantages of using whey instead of skimmed-milk powder in the treatment of children with moderate malnutrition.

Meat

The word "meat" refers to skeletal muscle and related fat. Muscle tissue has a very high content of protein, about 20% in fresh and 80% in dried meat. Its protein contains all of the essential amino acids, and it is a good source of zinc, phosphorus, iron, vitamin B_{12}, selenium, niacin, vitamin B_6, and riboflavin (**table 24**). Furthermore, it contains the "meat factor" (described in the section on Bioactive Substances), which enhances nonheme iron absorption. Meat contains no fiber, has a negligible content of carbohydrates, and has a relatively high content of fat. However, the fat content of meat can vary, depending on the type of animal and how it was raised, the feed, and the part of the body. Game meat is typically leaner than meat from farm animals and has a more favorable fatty acid composition, with more n-3 fatty acids.

Meat is an expensive food, but the price varies considerably depending on local availability, whether it comes from cattle, sheep, goats, or pigs, and the cut of the meat. In some countries, dried meat is available as an alternative to fresh meat. Meat is a very valuable ingredient in diets for children with moderate malnutrition. The most important characteristic of meat, as compared with the other important animal-source food, milk, is its positive effects on iron and zinc status.

Offal

The edible parts of animals can be divided into meat (i.e., skeletal muscle) and other (nonmeat) parts, collectively called offal. The offal includes internal organs and external parts. The internal organs comprise the heart, liver, kidneys, spleen, tongue, and lungs (red offal), and also the brain, marrow, stomach and intestines, testicles, and thymus (white offal). External parts include the ears, eyes, snout, palate, tail, and feet. The most important organs are the liver, kidney, and intestines.

Liver is a rich source of iron and zinc, most of the B vitamins including folate, and vitamins A and D and also has a high content of the "meat factor" (**table 24**). Liver can also have a high content of contaminants. If liver is available and affordable, it is highly recommended that small amounts be added to the diet of children with moderate malnutrition. Even if it is not possible to supply liver daily, it will still be a valuable ingredient even if it is only given one or two times a month. In a study from Peru, the use of liver in complementary food was an important part of an educational intervention aimed at parents of infants and young children [281]. Those randomized to the intervention had higher intakes of iron and zinc, better weight and length gain, and less stunting. The extent to which offal is used for human consumption differs between cultures. What is considered a delicacy in one culture may be considered unacceptable in another culture. In low-income countries, better utilization of all edible parts of animals may considerably increase the intake of important nutrients. Offal typically has a low market value, and most offal has a high nutritional value. Greater use of acceptable and appropriate offal in feeding of infants and young children should be considered, especially if there is no or very low intake of animal-source foods.

Blood

Blood from animals is used in foods in some cultures, either as an ingredient in sausages or as a drink with milk in some populations, whereas it is not accepted in other populations for cultural reasons. Dried blood or serum has been produced commercially as an ingredient but has not been widely used. However, where blood or serum is culturally acceptable, it can be a nutritious and cheap ingredient in food for infants and children with moderate malnutrition, as it is a good source of iron, vitamin B_{12}, protein, and other nutrients (**table 24**). In Chile a cereal fortified with bovine hemoglobin concentrate (14 mg of iron/100 mg of powder) seemed to reduce the risk of iron deficiency when given to healthy breastfed infants from the age of 4 months to the age of 12 months [282]. Among early-weaned pigs, supplementation with different fractions of spray-dried plasma from pigs as well as cows improved dietary intake and growth, and the IgG fraction was considered to be responsible for the beneficial effects [283]. In a

TABLE 24. Macronutrient and energy contents and nutrient densities of selected meats and other animal products (values/100 g)

	Macronutrients and energy					Nutrient density/1,000 kcal							
Animal product	Energy total (kcal/ 100 g)	Protein (g/100 g)	Lipid (g/100 g)	Protein (E%)	Lipid (E%)	Protein (g)	Vitamin A (μg)	Vitamin B_{12} (μg)	Vitamin B_1 (mg)	Folate (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)
Recommended nutrient density/1,000 kcal[a]						24	960	1.0	0.6	220	600	9	13
Beef													
Lean[b]	126	21.7	3.5	69.0	25.1	173	45	2.7	0.4	5.7	4.0	3.0	6.8
Fat [b]	317	16.4	28.4	20.7	80.7	52	18	1.1	0.2	2.3	3.0	2.3	2.9
Blood	92	21.1		92.1	—	230	0	—	0.1	—	5.2	115	—
Heart	102	19.2	2.4	75.4	21.2	188	16	23	1.2	9.3	21	11.7	4.7
Liver	146	22.2	3.5	60.7	21.5	152	29,000	179	0.5	368	11	11.1	7.7
Stomach	97	16.1	3.6	66.1	33.3	165	2	—	0.0	24.4	37	4.6	6.6
Pork													
Lean[b]	107	22.2	1.9	83.3	16.0	208	0	1.3	1.8	4.7	16	1.6	8.0
Fat [b]	200	28.7	9.6	57.4	43.2	144	8	0.8	0.7	3.6	8.3	3.0	4.9
Poultry													
Chicken[b]	167	31.2	4.6	74.8	24.8	187	34	0.5	0.1	24.3	16	1.1	3.6
Duck (meat)[b]	119	18.3	5.1	61.5	38.6	154	48	0.8	0.7	96.0	22	2.4	2.7
Others													
Goat	190	27.1	9.2	56.9	43.5	142	40	—	0.1	6.3	11	2.3	3.3
Goat blood	98	21.4	0.3	87.7	2.8	219	0	—	0.0	—	15	14.1	—
Rabbit[b]	187	26.9	8.9	57.5	42.8	144	4	13	0.1	10.2	15	1.8	1.5
Mutton lean[b]	179	27.0	7.9	60.3	39.7	151	60	0.0	6.6	29.3	28	3.1	7.4

a. Values from Golden [4].

b. Source: National Food Institute (Denmark) [28] study among 6- to 7-month-old Guatemalan infants, those receiving a daily supplement with a bovine serum concentrate (as a source of immunoglobulins) for 8 months had the same growth and morbidity as those receiving a whey protein concentrate [284].

Conclusions and recommendations on meat, offal, and blood

- The intake of meat or offal should be promoted.
- Meat is an excellent source of high-quality protein and several important micronutrients and has a particular positive effect on iron status.
- Meat is expensive and, in many settings, not easily available, and it has to be prepared in special ways (e.g., by mincing) to be acceptable to young children.
- Liver is an exceptionally rich source of iron, zinc, vitamin A, and other nutrients and should be promoted as an important part of the diet.
- The potential of increasing the use of offal and blood should be explored, where culturally acceptable, as these may be a low-cost source of animal food.

Eggs

Eggs from chickens and other birds have a very high nutritional value, as they provide all the nutrients necessary for a bird embryo to develop. Eggs are often more easily available at the community level than milk and meat, have a lower cost, and can be bought in small quantities. More than half the energy in eggs comes from the fat in the yolk; 100 g of chicken egg contains approximately 10 g of fat. An average chicken egg contains about 5 to 6 g of protein and 4 to 5 g of high-quality fat. About 20% of the fatty acids are PUFAs, with a favorable n-6/n-3 fatty acid ratio of 4 to 5. Eggs contain a significant amount of cholesterol, about 0.5 g/100 g. However, this is not likely to have negative effects in infants and young children. Breastmilk also contains high levels of cholesterol, which may play a role in early development. Egg white consists primarily of water and protein (13%) and contains little fat and carbohydrate. Egg protein is of very high quality, with a PDCAAS of 118%. The most important micronutrients are vitamin A, thiamine, and riboflavin, and also some vitamin D. Egg contains iron, but the availability is poor, and egg white also seems to have a negative effect on absorption of nonheme iron from other foods [285]. Giving one or two eggs a day to a child with moderate malnutrition will be a valuable contribution to the requirements.

Conclusions and recommendations on eggs

- Eggs contain high amounts of high-quality protein and fat, preformed vitamin A, and other important micronutrients.
- Eggs are a valuable food to give to moderately malnourished children and should be promoted.

Fish

All fish are a rich source of high-quality protein and provide a range of other important nutrients, depending on species and processing. The fat content in fish species ranges from less than 1 to more than 30 g of fat/100 g of raw fish. Fatty fish are a valuable source of n-3 LCPUFAs. Small, soft-boned fish that are eaten with the bones are an excellent source of calcium and phosphorus. Furthermore, fish is a good source of zinc and bioavailable iron, and fish enhances nonheme iron absorption due to the "meat-factor" effect.

In all parts of the world, there is a general consumer preference for large-sized fish. Consequently, small fish generally have a relatively low market price and are therefore more accessible to the poor. In general, small-sized fish are nutritionally superior to large fish because the edible parts of small fish include more diverse tissues, such as the head, bones, and viscera, as compared with large fish, where muscle tissue contributes most to the edible parts [286].

In coastal areas and in regions with rich inland water resources, such as the large river basins of Asia and Africa (Ganges, Mekong, Nile, etc.), fresh fish is widely available, strongly impacted by seasonal and annual variation. In such areas, fish is often the main or only accessible animal food for poor households [287]. The fish species found in the diet in these regions reflect the biological diversity of the natural environment and typically include a variety of small fish species. As an example, poor rural households in Bangladesh typically consume more than 50 different fish species over a year, and a single meal can include mixed batches of 5 to 10 different fish species [286]. Fresh fish is a highly perishable commodity, and the price is highly fluctuating according to availability, market structure, and the quality of the fish.

Nutritional contribution

The energy density in fish is determined mainly by the fat content and ranges from 80 kcal/100 g of raw fish in lean fish such as cod and other species with less than 1% fat, to 360 kcal/100 g of raw fish in fatty fish such as eel, reaching to more than 30% fat in raw fish [288]. In addition to interspecies variation in fat content, the specific content in fish is also influenced by physiological conditions (e.g., reproductive cycles) and feeding conditions. For example, the fat content in Peruvian anchovy (*Engraulis ringens*) after a stress period due to the El Niño phenomenon fell from 11% fat to less than 1% in raw fish [289].

The protein content in fish species, with few exceptions, is in the range of 15% to 25%, and most species are in the range of 18% to 20%. The protein quality is in general high. The PDCAAS has been reported for a few species as being similar to that of meat, i.e., in the range of 70% to 100%.

The fatty acid composition of freshwater fish varies between different aquatic environments (due to diet, temperature, salinity, etc.) [290]. No data on the fatty acid composition of small freshwater fish species are available, but the lipid quality of the larger tropical freshwater fish is comparable to that of temperate freshwater fish [290]. Roughly estimated, the PUFA content of freshwater fish is around 25% of the fat, one- third of which is n-3 PUFA, and half of the n-3 PUFA is long-chain PUFA.

Fish is a good dietary source of micronutrients, especially iron and zinc. A proportion of the iron, ranging from 30% to 80%, is present in highly bioavailable forms, such as heme iron or other high-molecular-weight organic compounds, such as ferritin [291]. In general, the iron content in fish is less than that in red meat and is similar to the content in chicken and pork [292]. The specific iron content varies with species and with the cleaning practices that determine which parts of the fish are edible [292–294]. Some small freshwater fish species of the genus *Esomus* have been found to have an iron content (12 mg/100 g of edible parts) four to five times higher than that of other small species from the same aquatic environment [291].

Small, soft-boned fish are a good calcium source. The bioavailability of calcium from the soft-boned species *Amblypharyngodon mola,* which is one of many commonly consumed small fish species in South Asia, has been shown to be similar to the bioavailability of calcium from milk [295]. The acceptability of consumption of bones is determined by the "hardness" of the bones, and "hard-boned" small fish species contribute less dietary calcium because the bones are discarded as plate waste [296]. In **table 25**, the calcium contribution from small fish is corrected by a "plate waste factor" to compensate for the measured calcium content of bones discarded as plate waste.

Fish liver is well known as a rich source of vitamin A and D, while fish muscle tissues have low contents of these vitamins. The vitamin A content in small fish has been shown to vary by a factor of more than 100 between species. In vitamin A–rich species, a large proportion of the vitamin A is located in the eyes of the fish, and the traditional cleaning practices as a determinant of the edible parts are therefore a crucial parameter for the dietary contribution of vitamin A from such species [293, 297]. Vitamin A in fish is present in two forms: vitamin A_1 (retinoids) and vitamin A_2 (dehydroretinoids). The biological function of vitamin A_2 is calculated as 40% of that of vitamin A_1.

There are only a few intervention studies with fish in children. In a study in Ghana, moderately malnourished children were fed a maize-based complementary diet with powdered dried fish (20% on a dry weight basis) added to either a traditional maize porridge, koko, or a complementary food, Weanimix, which contained 75% to 80% maize, 10% to 15% soybeans or cowpeas, and 10% peanuts [298]. Other groups received either Weanimix alone or Weanimix with a micronutrient supplement. The children were fed the diet from 6 to 12 months of age. The growth of the children was similar in all groups, but they all received a diet with improved protein quality. Also, powdered dried fish did not improve the iron stores of the children. In a recent study from South Africa, schoolchildren were given a bread spread with fish flour from a marine source or a placebo spread [53]. Those receiving the fish spread had an improvement in verbal learning and memory.

Processed fish

Processing technologies to expand the shelf-life of fish are drying, salting, smoking, and fermentation. Icing and freezing for preservation of fish are rarely an option in low-income countries, and if a cooling chain is available, there is an inherent problem of ensuring that it is intact from the producer to the end user. All fish-processing methods affect the organoleptic qualities (taste, smell, and appearance) as well as the nutritional quality of the fish.

Sun-drying. Sun-drying of fish is widely practiced in Asia and Africa, and dried fish is in most cultures an accepted ingredient in mixed dishes. The organoleptic quality of traditional sun-dried fish is highly variable, and caution should be exercised to identify suppliers of products of good quality The nutritional value of dried fish is similar to that of fresh fish for protein, fat, and minerals (iron, zinc, and calcium), whereas for species with a high vitamin A content, the vitamin A is almost totally destroyed by sun-drying [297].

Small dried fish can be ground to powder and added to foods such as porridge. Dried fish is available in many settings and is an affordable animal food that can be added to diets of children with moderate malnutrition.

Salting. Salting is widely used for preservation. The salt in fish can be washed out before use, and the original nutritional composition is largely reconstituted. The food safety of salted fish is a concern, as contamination with pathogenic bacteria is a risk, particularly when the fish is processed in a warm climate without cooling opportunities. Even if most of the salt is washed out, there will still be a relatively high content of salt, making salted fish an inappropriate food, since the salt content in the diet of malnourished children should be kept low [4] .

Fermenting. A large number of traditional fermented fish products are known in most fish-producing regions in the world. Traditional processing methods are highly variable, ranging from light salting of products with a few days of shelf-life to processing with a higher level of salting of products that are preserved for several months. The nutritional value of fermented fish products is comparable to that of fresh fish. However, the suitability of fermented fish in diets for children

TABLE 25. Macronutrient and energy contents and nutrient densities in freshwater and marine fish species (values/100 g raw fish)

Fish species	Energy and macronutrients							Nutrient density/1,000 kcal						
	Energy (kcal)	Protein (E%)	Lipid (E%)	Protein (g)	Lipid (g)	PUFA (%)	n-6:n-3 (g:g)	Vitamin A (µg RAE)[a]	Vitamin B_{12} (µg)	Calcium in raw, edible parts (mg)[b]	Calcium corrected for plate waste (mg)[c]	Iron (mg)	Zinc (mg)
Recommended nutrient density[d]								960	1.0	600	600	9	13
Marine species[b]													
Herring (*Clupea harengus*)	201	36	65	18	14.5	2.7	0.1	151	46.1	249	—	6.5	4.2
Saithe/pollock (*Pollachius virens*)	81	96	35	19	3.1	0.1	> 0.1	37	16.1	99	—	2.5	3.7
Haddock (*Melanogrammus aeglefinus*)	85	89	11	19	1.0	0.5	> 0.1	0	11.7	211	—	7.0	3.5
Small freshwater species[e]													
Mola (*Amblypharyngodon mola)*	112	69	16	16–18	4.4	—	—	23,937	—	7,619	6,931	51.0	28.6
Darkina (*Esomus danricus*)	113	68	16	16–18	4.5	—	—	7,801	—	7,899	6,871	106	35.5
Puti (*Puntius sophore*)	135	57	21	16-18	7.1	—	—	446	—	8,697	5,823	22.0	23.0
Cultured freshwater species[e]													
Rui *(Labeo rohita)*	111	69	16	—	4.3	25[f]	0.9[f]	—	—	7,712	774	—	—
Silver carp (*Hypophthamichthys molitrix*)	112	69	16	—	4.4			—	—	8,065	322	51.6	—
Common carp (*Cyprinus carpio*)	123	63	19	18	5.7	30[g]	1.5	309	12.5	—	334	10.0	12.0
Tilapia (*Oreochromis niloticus*)	89	86	8	20	1.7	23[h]	2.8	336	17.7	—	112	6.0	3.7

PUFA, polyunsaturated fatty acid; RAE, retinol activity equivalent

a. Vitamin A contents in fish species are calculated as RAEs from contents of retinoids (vitamin A_1) and dehydroretinoids (vitamin A_2) [297].

b. Source: US Department of Agriculture [27].

c. Corrected according to Roos et al. [296].

d. Values from Golden [4].

e. Values from Roos et al. [286] and unpublished data, unless otherwise noted.

f. Values from Ackman [306].

g. Carp in Beysehir Lake in Turkey contain from 29% to 43% PUFA, depending on the time of year [307].

h. Tilapia from the Nile contain 20% PUFA [308], while tilapia from Lake Chamo in Ethiopia contain around 26% PUFA [290].

with moderate malnutrition has to be considered in terms of the organoleptic qualities of the products and the cultural habits for the specific local products, and in terms of food safety issues. Food safety is related to the risk of growth of pathogenic bacteria, and also in some regions, especially in Asia, to the risk of infections with fishborne zoonotic parasites such as liver flukes [299]. The risk of infections with fishborne zoonotic parasites is eliminated by heating the fish and is therefore relevant only if a fish product is consumed raw or insufficiently heated. Raw, fermented fish may contain thiaminase, which can reduce the effect of thiamine pyrophosphate. Thiaminase is destroyed by heating [300].

Tinned fish. Tinned fish is a convenient substitute for fresh fish. Fat fish such as tuna and mackerel are energy dense, especially when preserved in oil. The nutritional profile of tinned fish is largely similar to that of fresh fish, but the lipid profile can change slightly in the tinning process [301] and after 3 to 6 months of storage [302]. Tinned fish cannot be stored after opening because of the risk of bacterial contamination [303].

Fish protein concentrate. Fish protein concentrate is a powdered product made from whole fish, with a high protein concentration. However, fish protein concentrate is not well adapted for human consumption, because the taste and smell are unacceptable, even in refined products. Decades ago, fish protein concentrate was considered for use as a protein supplement for malnourished children. In one early study, fish protein concentrate was compared with skimmed milk for the ability to induce weight gain and rehabilitation in children suffering from kwashiorkor [304]. It was concluded that fish protein concentrate had an impact largely comparable to that of skimmed-milk powder, but the fish protein concentrate diet was not well accepted by the majority of the children. In a similar study in measles-infected children, the tolerance of the fish protein concentrate diet was reported to be acceptable, and the nutritional value was comparable to that of milk powder [305]. However, at present, there are no practical applications of fish protein concentrate in feeding children with moderate malnutrition, due to its organoleptic qualities.

Contamination

The accumulation of mercury in fatty fish is a potential health risk. Some high-income countries have issued guidelines for restricted intake of fatty fish by pregnant women and children to avoid exposure to toxic substances such as mercury. Accumulation of polychlorinated biphenyls (PCBs), lead, arsenic, and cadmium in fish stocks may pose a health hazard. Fish originating from polluted environments may be safe for consumption, especially lean fish with a short life cycle that are less likely to accumulate contaminants. The main contamination risks are from carnivorous fatty fish with long life cycles, such as tuna; in feeding children with moderate malnutrition, caution should be exercised to avoid high and frequent intake of tinned tuna or mackerel, for example, unless the product is known to have a low level of contamination. Many small freshwater and coastal fish are lean with short life cycles, which prevents the accumulation of most potential contaminants.

The use of pesticides in agricultural production may be hazardous to fish living in rice fields. It is usually not a major problem in other settings. Caution should be exercised in the use of toxic substances in local postharvest preservation, such as the use of DDT to prevent insect infestation during sun-drying of fish or the use of diluted formalin for preservation of “fresh” fish. These contamination risks should be avoided by using trustworthy suppliers.

Conclusions and recommendations on fish

- Fish is a good source of high-quality protein, n-3 fatty acids, and micronutrients.
- Small fish that are consumed whole are an especially good source of highly bioavailable calcium, iron, zinc, and vitamin A.
- Vitamin A is not preserved in sun-dried fish.
- Fillets from large fish have low to moderate levels of iron and zinc.
- Fish enhances absorption of nonheme iron. The enhancing effect is about half that of meat.
- Fish is beneficial to add to the diet as an animal-source food, replacing meat. The nutritional impact of adding small amounts of fish (10 to 50 g) to a meal remains to be documented.
- The issues of food safety and contamination should be considered if fish are used in the diets of children with moderate malnutrition.

Other animal-source foods

Lack of animal-source foods in the diet of people in low-income populations contributes to undernutrition and especially the widespread deficiencies of iron, zinc, and vitamin A. Conventional animal-source foods (eggs, meat, and organs from cows, goats, sheep, pigs, poultry, and fish) are often inaccessible or unaffordable.

Other animal-source foods with high contents and bioavailability of important micronutrients may be readily available and affordable but underutilized. Some of these foods cannot be promoted, as they may be culturally unacceptable or come from animals at risk of extinction. Foods that could be promoted include low-valued parts of domestic animals, as well as snakes, rodents, frogs, snails, and insects from fields, uncultivated land and forest, and aquatic environments.

For example, insects have constituted a fundamental part of the diet among previous and contemporary hunter-gatherers [309]. Although entomophagy (insect-eating) declined with the development of agriculture in most regions, reinforced by modern prejudice against insects, it has remained part of traditional knowledge among subsistence farmers [310]. Insects are still occasionally collected and eaten, especially in times of drought when modern crops fail. For example, more than 65 species of insects have been reported as food in the Democratic Republic of the Congo [310].

The nutritional importance of entomophagy has not been fully appreciated, since the focus has been on protein content. However, the very high contents of important micronutrients in insects, in particular iron and zinc, may be of considerably greater importance. The bioavailability of iron and zinc in insects, and whether insects may have the "meat factor" effects, remains to be studied. A survey among elderly Luo in western Kenya identified five commonly eaten insect species, including ants, termites, and crickets [311]. The iron and zinc contents were up to 1,562 and 341 mg/100 g dry matter, respectively. Although most insects are only available for short periods in specific seasons, they can be dried and kept for later use. In South Africa, it has been estimated that 16,000 tonnes of dried mopane caterpillars are sold each year.

Even relatively small amounts of insects may contribute considerably to the intake of protein and important micronutrients in complementary diets and in diets for malnourished children, including those with HIV infection, where a high nutrient density is required.

Conclusions and recommendations on other animal-source foods

- » Snakes, rodents, frogs, snails, and insects may in some settings constitute an important and underutilized resource.
- » Insects may have a very high content of protein as well as of minerals such as iron and zinc.
- » Small amounts of these other animal-source foods can provide an important contribution to the diets of children with moderate malnutrition, if culturally acceptable.

Oils and fats

Vegetable oils and fats are important ingredients in the diet of children with moderate malnutrition. They are expensive ingredients, and often the intake is low in populations with high rates of malnutrition. Apart from being low in fat, the basic diet of malnourished children appears to be specifically low in n-3 PUFAs, whereas many of the oils and staple foods supply some n-6 PUFAs (**Tables 12, 15,** and **26**). These aspects are discussed in the sections on Fat Composition of the Diet which also include the recommendations for intakes of n-6 and n-3 PUFAs for moderately malnourished children (5 g of n-6 PUFA/1,000 kcal and 0.55 g of n-3 PUFA/1,000 kcal). In this section, the characteristics and the role of oils and fats in diets for moderately malnourished children are discussed.

The potential health effects of an optimal intake of

TABLE 26. Fatty acid composition of common edible fats and oils (values in g/100g)[a]

Fat or oil	SFA	MUFA	PUFA	n-6 PUFA	n-3 PUFA	n-6/n-3	Dominant FA (>10%)
Plant source							
Coconut oil	86.5	5.8	1.8	1.8	0.0		12:0 and 14:0
Palm oil	49.3	37.0	9.3	9.1	0.2	45.5	16:0 and 18:1
Olive oil	13.8	73.0	10.5	9.8	0.8	12.8	18:1
Sunflower oil, high oleic	9.7	83.6	3.8	3.6	0.2	18.8	18:1
Sunflower oil (LA < 60%)	10.1	45.4	40.1	39.8	0.2	199	18:1 and 18:2
Sunflower oil (LA approx. 65%)	10.3	19.5	65.7	65.7	0.0		18:2 and 18:1
Groundnut/peanut oil	16.9	46.2	32.0	32.0	0.0		18:1 and 18:2
Grapeseed oil	9.6	16.1	69.9	69.6	0.1	696	18:2 and 18:1
Sesame oil	14.2	39.7	41.7	41.3	0.3	138	18:2 and 18:1
Maize/corn oil	13.0	27.6	54.7	53.2	1.2	45.8	18:2, 18:1. and 16:0
Soybean oil	15.7	22.8	57.7	50.4	6.8	7.4	18:2, 18:1. and 16:0
Canola/rapeseed oil	6.4	55.4	33.2	22.1	11.1	1.9	18:1 and 18:2
Flaxseed oil	9.4	20.2	66.1	12.7	53.3	0.2	18:3, 18:1. and 18:2
Animal source							
Butter, salted	51.4	21.0	3.0	2.7	0.3	8.8	14:0, 16:0, 18:0. and 18:1
Lard	39.2	45.1	11.2	10.2	1.0	10.2	16:1, 16:0. and 18:0
Fish oil	29.1	23.7	42.3	3.6	38.7	0.09	22:5n-3, 16:0. and 22:6n-3

FA, fatty acid; LA, linoleic acid (18:2n-6); MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acid

a. Fatty acids are given as number of carbon atoms in chain:number of double bonds. Sources: US Department of Agriculture [27], NutriSurvey [315].

PUFAs and the large variation in PUFA content of different vegetable oils make the source of vegetable oil used in foods for children with moderate malnutrition important. Food declarations often do not mention the kind of vegetable oil that is used. This is not satisfactory. The source and amount of fat should be declared in processed foods used for children with moderate malnutrition.

Some of the oils that are frequently used in low-income countries, such as palm oil and coconut oil, have a high content of saturated fatty acids. These fatty acids provide a good source of energy but do not provide essential fatty acids. The potential negative effect of a high intake of saturated fat, which is a concern in high-income countries, is not likely to be a problem in the treatment of malnourished children. Palm oil is characterized by a high content of palmitic acid (about 45%) and has a very low content of n-3 PUFAs and thus a high n-6/n-3 PUFA ratio of about 45. Unheated palm oil is red because of a high content of β-carotene. Palm kernel oil, which is made from palm seeds and not palm fruit, as is palm oil, has a very different fatty acid composition. As in coconut oil, more than 80% of the fatty acids in palm kernel oil are saturated fatty acids; most of these are the medium-chain fatty acids lauric and myristic acid, and only about 8% is palmitic acid. Compared with red palm oil, palm kernel oil and coconut oil have much lower contents of oleic acid and PUFAs.

Most other common vegetable oils have a high content of either oleic acid (18:1n-9), linoleic acid (18:2n-6), or both (**table 26**). Oleic acid acts as a competitor in the metabolic processing of the essential fatty acids, linoleic acid and α-linolenic acid (18:3n-3), and as such can to some extent possibly spare the essential fatty acids for their essential functions [312]. The oleic acid–rich oils may thus be a good choice to use with other more essential fatty acid rich oils. Only a few of the common vegetable oils contain a significant amount of α-linolenic acid; the most common is soybean oil, but canola (rapeseed) oil, walnut oil, and flaxseed oil also contain significant amounts. However, none of these vegetable oils contain n-3 LCPUFAs (eicosapentaenoic acid and docosahexaenoic acid), which are only supplied in large quantities from marine foods. The n-3 PUFA–containing oils may be the best choice for malnourished children. The needs for n-3 PUFAs could be fulfilled either by giving soybean oil as the main fat source or by supplying some flaxseed oil in combination with a vegetable oil that is available and affordable. To supply the 0.55 g of n-3 PUFA/1,000 kcal needed, 5 mL of rapeseed oil/1,000 kcal or 8 mL of soybean oil/1,000 kcal is needed. To cover the requirements of n-3 PUFA with other vegetable oils with lower n-3 PUFA content is not realistic. For corn oil it would take 70 mL of oil/1,000 kcal, and the recommended n-6/n-3 ratio would never be reached if large quantities of corn oil were used.

Soybean oil is of high quality, as it contains a high proportion of unsaturated fatty acids; the most important ones being: PUFAs; linoleic acid, α-linolenic acid, and oleic acid (18:1n-9). Soybean oil contains a high amount of n-6 PUFA, less n-3 PUFA, but compared with other oils a relatively high content of n-3 PUFA (100 g of soybean oil contain 7 g α-linolenic acid and 51 g of linoleic acid) resulting in an n-6/n-3 PUFA ratio of 7, close to the recommended ratio of 6 [4]. In comparison, flaxseed oil, also called linseed oil, has a very high n-3 PUFA (α-linolenic acid) content and thereby a n-6/n-3 PUFA ratio of 0.2. The n-3 PUFA content of rapeseed oil (canola oil) is between the two with respect to the ratio between n-3 PUFA and n-6 PUFA; it has a high content of oleic acid and is used increasingly as the main vegetable oil in many European countries. Corn oil, sunflower oil, grapeseed oil, and peanut oil are unbalanced sources of essential fatty acids, with high amounts of n-6 PUFA and only a little n-3 PUFA. Using these oils will make the essential fatty acid intake more unbalanced.

Rapeseed oil may have high levels of erucic acid, which may have negative health effects, but some types of rapeseed oil, such as canola oil, have low levels of erucic acid. The European Union directive for the composition of infant formula states that the amount of erucic acid should not be above 1% of the total fat content. It therefore seems reasonable to adopt the same limit for infants and children with moderate malnutrition. Flaxseed oil has traditionally been used for wood finishing but is now becoming a more common food supplement sold in health-food shops. It is rapidly oxidized and may produce toxic oxidation products if antioxidants are not added. Although flaxseed oil is a rich source of n-3 PUFA, it should not be used for infants and young children before potential negative effects have been examined further.

Palm oil, soybean oil, and rapeseed oil are among the oils produced in the largest amounts globally. There are only moderate differences in price among the three types of vegetable oil used commonly by the World Food Programme: soybean oil, palm oil, and sunflower oil. Based on prices from January 2009, the cheapest oil was palm oil (about US$800/ton), with soybean oil and sunflower oil being about 20% more expensive and rapeseed oil about 30% more expensive. To cover the PUFA requirements, soybean oil or rapeseed oil, which at present is only about 10% more expensive than palm oil, are the best choices.

Vegetable oils can be hydrogenated to produce a solid or a semisolid fat, which can have technical advantages in food production, such as in baking. When a vegetable oil is hydrogenated, the unsaturated fat is transformed into saturated fat, which increases the melting point of the fat. If the vegetable oil is only partially hydrogenated, *trans*-fatty acids are produced, which seem to have several adverse health effects, especially on cardiovascular risk factors, and may counteract the effects of *cis*-unsaturated fatty acids [313]. Partially hydrogenated fat is not allowed in the Codex Alimentarius standard for cereal-based infant foods [314]. Thus, partially hydrogenated vegetable oils should not be used in diets for children with moderate malnutrition.

The most common animal fats include butter, ghee, lard, and fish oil. Ghee is boiled, clarified butter without the protein from the butter, and lard is pure fat from the pig. Lard has considerably more n-3 PUFA than butter (**table 26**), and both lard and butter have n-6/n-3 ratios of 9 to 10, which is within the recommended range. However, it is not realistic to cover the requirements of PUFA from these fat sources, since too large amounts would be needed. Fish oil has a very high content of n-3 PUFA, about 35%. To cover the recommended intake of n-3 PUFA, only about 1.5 mL of fish oil/1,000 kcal is needed. Since fish oil contains n-3 PUFA in its long-chained forms, docosahexaenoic acid and eicosapentaenoic acid, this amount is likely to be more effective than equivalent doses of n-3 PUFA with only α-linolenic acid.

Conclusions and recommendations on oils and fats

- Vegetable oils are important ingredients in diets for malnourished children, as they supply both energy and essential fatty acids.
- Soybean and rapeseed oil are the oils that best cover the requirements of PUFAs at a reasonable cost.
- Adding about 15 mL (1 tablespoon) of soybean oil daily to the diet of a malnourished child will cover the requirements of essential fatty acids and will supply about 10% of the energy requirements.
- If vegetable oils with low contents of n-3 PUFAs are used, the n-3 PUFA requirements could be covered by adding small amounts of fish oil.
- The source of vegetable oil used in processed food for children with moderate malnutrition should be declared.
- Partially hydrogenated vegetable oils should not be used in diets for children with moderate malnutrition because of potential adverse effects of *trans*-fatty acids.

Research recommendations

- The effects of an optimal n-3 fatty acid intake in children with moderate malnutrition should be studied.

Sugar

Sugar contributes only energy and no other nutrients, such as vitamins or minerals. Brown sugar, which typically is a mix of white sugar and molasses, contains some iron and calcium. Molasses contains 4.7 mg of iron and 205 mg of calcium per 100 g [27], but it constitutes only about 5% of brown sugar and is not available at a reasonable price. The energy content of sugar is a little less than half that of fat. Still, added sugars have a relatively high energy density compared with many other foods, since the water content of sugar is zero. Adding sugar to foods increases the energy density but at the same time decreases the nutrient density and increases the osmolarity. The higher energy density is likely to have a positive influence on energy intake, an effect that is worrying in high-income societies with a growing prevalence of obesity. In the treatment of children with wasting who have an increased energy need, this increase in energy intake is an advantage. Adding a high sugar content to diets for children with moderate stunting who need treatment over a long period may impose a risk of overweight. Another important aspect of added sugar is how it affects taste. The sweet taste is likely to improve the palatability and thereby the acceptability of the food. Adding sugar may therefore help to increase energy intake both through increased energy density and through an improved taste, an effect that may be especially important in situations where bulky foods are fed or appetite is poor. However, when sugar is used for a longer period of time, there is a risk of reinforcing a preference for sweet foods, resulting in too high an energy intake later in life.

Adding sugar to a food or a diet reduces the nutrient density, as it provides no vitamins and minerals. Studies from high-income countries have shown that a high sugar intake (above 15 E%) has a negative influence on certain important nutrients, such as zinc, where the nutrient density (mg/10 MJ) was below the recommended level [316, 317]. In 2003, the report of a Joint WHO/FAO Expert Consultation on Diet, Nutrition and Prevention of Chronic Diseases [318] recommended that added sugar intake should not go above 10 E% at the population level. There are no firm scientific data to support the level of 10 E%, but rather it has been chosen as a prudent level. In treating children with moderate malnutrition, 10 E% seems to be a reasonable maximum level. If more than 10 E% is added to a food or diet, there is a need to ensure that the content of vitamins and minerals is sufficient. In treatment of moderate wasting for a limited period, a content higher than 10 E%, but not more than 20 E%, may be acceptable. Sugar adds considerably to the osmolarity of the food, which should also be taken into consideration.

A high and frequent intake of sugar over a long time may increase the risk of caries, especially in situations with poor oral hygiene [318]. However, this may not be important during shorter periods of rehabilitation. Giving a diet with a high sugar content over a long period may also make it difficult for the child later to accept a diet with no or very low sugar content. This problem, which has been observed after treatment of severe malnutrition, should be investigated further.

Conclusions and recommendations on sugar

- Adding sugar increases energy intake by increasing energy density and improving taste but reduces the nutrient density of the food.
- Adding sugar may increase the risk of caries.
- The amount of sugar should generally not exceed 10 E%, although 20 E% for up to a few weeks may be acceptable for treatment of wasted children.

Research recommendations

- It should be investigated whether children have difficulties accepting a normal diet with no or very little sugar after a period of treatment with a high sugar intake.

Salt

Malnourished children have only a low requirement of sodium, since they are in a sodium-retaining state [4]. A high sodium intake will increase the renal solute load, which may result in hypernatremic dehydration. Furthermore, a high sodium intake may result in heart failure. Sodium adds taste to a meal, but this is not likely to be important for infants and young children. Thus, there is no need to add salt (sodium chloride) to the diet of an infant or child with moderate malnutrition. Salt is used as a vehicle for iodine fortification, but children should have their iodine requirement covered in another way.

Conclusions and recommendations on salt intake

- Salt (sodium chloride) should not be added to the diet of children with moderate malnutrition.

Other issues

Appetite

There are some studies suggesting that different foods have different effects on appetite, apart from the effect of the energy content. This is an area that has been studied in detail in relation to obesity, but it is also an area that is relevant for malnutrition [22]. To our knowledge, there is not much information available on appetite in relation to treatment of malnutrition, although this is an area with potentially high importance. Some studies suggest that a high protein content in a diet will have a negative effect on energy intake [22], which could be an important reason, apart from cost, not to have too high a protein content in diets for malnourished children. It has also been suggested that beans can have a negative effect on appetite, which may be caused by colonic fermentation of oligosaccharides that produces discomfort because of gas production and slowing of gut transit time [319]. This could be another reason for not using or using only small amounts of beans and other legumes in diets for children with moderate malnutrition. Other foods have been suggested to influence appetite less than would have been expected from the energy content. Some studies have shown that liquid sugar, as in soft drinks, and especially fructose–glucose syrup, has a limited effect on appetite and may therefore result in increased energy intake and weight gain [320, 321]. However, liquid sugar is not suitable for long-term use in children with moderate malnutrition.

Conclusions and recommendations on appetite

- Some foods have an influence on appetite (positive or negative) beyond the effect of the energy content.
- Research is needed to assess the effects of different foods, ingredients, nutrients, and dietary diversity on appetite among malnourished children.

Cost

The cost of foods used for treating children with moderate malnutrition is an important aspect to consider. In particular, the differences in price between animal and nonanimal foods are considerable and need to be taken into consideration when deciding which foods to recommend. In balancing the price against the effect, it should be considered that treating moderate malnutrition is likely to have a very important impact on health, by preventing the development of severe malnutrition, reducing morbidity and mortality, and improving mental and physical development. In this balance, it should also be taken into account that the foods used for treating severe malnutrition are based on milk, with 100% milk protein in F100 and 50% milk protein in RUTFs. Another important aspect is how much animal-source food is needed to make an impact. Here it is proposed that providing 25% to 33% of the protein from animal food sources can have an impact on growth. However, there is a need for more research to establish the minimum amount of animal-source food that makes a difference.

It is difficult to obtain comparable prices, since prices differ considerably with location, transport needed, subsidies, market situation, and season. A very rough estimate is that animal foods are 5 to 10 times more expensive, and that corn–soy blend and blended infant food are 2 to 3 times more expensive per energy unit than a basic staple food (Pieter Dijkhuizen, personal communication). In **table 27** we have given some examples of world market wholesale prices of different foods and commodities provided by the World Food Programme and have calculated for each food the price for energy (1,000 kcal) and for protein (24 g, which is the protein requirement per 1,000 kcal for children with moderate malnutrition [4]). Prices for both August

2008 and January 2009 are given, showing the dramatic fluctuations over a short period. The figures give a rough idea of the relative differences between relevant commodities and especially the difference between animal-source foods and other foods, bearing in mind that the difference between retail market prices and wholesale prices can be larger for animal-source foods. Cereals are the cheapest sources of energy, with maize the cheapest. Oils are about double the price, whereas soybeans and other legumes are at a higher level and animal foods are much higher. The cheapest sources of protein are soybeans, wheat, and maize. Interestingly, protein from rice is the same price as protein from chickpeas and green lentils and is about half the price of protein from skimmed-milk powder, which is one of the cheapest animal-source proteins. In estimating the cost of diets for children with moderate malnutrition, it is possible to take the requirements of all macro- and micronutrients into consideration using linear programming [322].

Conclusions and recommendations on cost

- Treating children with moderate malnutrition is important to prevent the development of severe acute malnutrition and severe stunting, which should be taken into consideration when evaluating the cost of the foods and ingredients used.
- An important aspect of the cost of the treatment is determining through intervention studies the amount of animal protein needed to make an impact on recovery.

Conclusions

It is not difficult to design an optimal diet for children with moderate malnutrition if the resources are available. The diet used for the treatment of severe malnutrition with a high content of animal food (milk powder) and a low content of fibers and antinutrients will also be effective in the treatment of moderate malnutrition. However, the ingredients in such a diet are expensive, are not available in most settings, and are not appropriate for a low-cost, sustainable, home-based treatment.

A main issue is to identify a cost-effective balance between the amount of animal foods—which have a high content of minerals important for growth (e.g., phosphate and zinc) and of protein of high quality (PDCAAS), with virtually no antinutrients, but which also have a high cost—and the amount of plant-based foods. This balance is especially important if the plant-based foods are unrefined cereals and legumes with a high content of fibers and antinutrients.

Infants and young children are more susceptible to the negative effects of antinutrients such as phytate and fibers, especially insoluble fibers, than older children. This is particularly crucial for malnourished children, who often have a compromised and thereby more vulnerable gastrointestinal tract.

The most used animal-source foods are milk, meat, and eggs. However, there are several other types of animal food sources that are often cheaper and can be valuable ingredients in the diet of moderately malnourished children if they are culturally acceptable. These include fish, especially small fish that are eaten whole and therefore have a high nutrient content, and

TABLE 27. Crude prices of energy (1,000 kcal) and protein (24 g) in selected commodities[a]

Commodity	Price US$/Mt Aug 2008	Price US$/Mt Jan 2009	Energy content (kcal/100 g)[b]	Protein content (g/100g)[b]	Energy price (US$/1,000 kcal) Jan 2009	Protein price (US$/24 g) Jan 2009
Wheat	340	225	330	12	0.07	0.05
Maize	240	190	360	9	0.05	0.05
Rice	490	340	360	8	0.09	0.10
Corn–soy blend	530	430	380	18	0.11	0.06
Soybeans	800	620	445	37	0.14	0.04
Chickpeas	925	775	364	19	0.21	0.10
Whole green lentils	1,000	825	352	26	0.23	0.08
Skimmed-milk powder	3,800	3,120	360	36	0.87	0.21
Whole-milk powder	4,250	4,250	500	25	0.85	0.41
Beef[c]	4,200	3,200	150	29	2.13	0.26
Soybean oil	1,875	1,150	880	0	0.13	NA
Sunflower oil	2,250	1,150	880	0	0.13	NA
Sugar	440	430	390	0	0.11	NA

Mt, metric ton; NA, not applicable

a. Prices are the median of the different prices given within each commodity from the World Food Programme FOB price lists from July and August 2008.

b. Energy and protein contents are taken from the tables in this review or from the USDA food table [27].

c. Beef prices are from the FAO International Commodity Price List (personal communication Tina van der Briel, November 2008)] other animal-source foods, such as insects, snakes, and rodents. Offal may also be an underutilized animal-source food. Milk seems to have a special effect in stimulating linear growth through an increased production of IGF-1.

When cereals and legumes constitute a large part of the diet, it is important that the contents of antinutrients and fibers are reduced through food processing. Soaking, malting, and fermentation reduce the contents of antinutrients. Milling also reduces the contents of antinutrients, but as the contents of both nutrients and antinutritional factors are high in the outer layer of grains, extensive milling will also reduce the nutrient density.

The fat content, and thereby the energy density, is typically low in a traditionally plant-based diet, and increasing the content of fat is a well-known and efficient way to increase nutrient density. To obtain an adequate energy density, the fat energy percentage should be at least 30 E% and preferably, especially for wasted children, between 35 and 45 E%. An issue that needs attention is the fat quality in the diets of children with moderate malnutrition. The content of PUFAs, especially n-3 fatty acids, is low in these plant-based diets and also in many oils. Several of the symptoms seen in children with moderate malnutrition could be caused by PUFA deficiency. Diets for moderately malnourished children should contain at least 4.5 E% of n-6 PUFAs and 0.5 E% of n-3 PUFAs. Soybean, rapeseed oil, and fish have high contents of n-3 fatty acids.

Research recommendations

There are still many unresolved aspects of the dietary treatment of children with moderate malnutrition that need to be investigated further, as highlighted in the sections with conclusions and recommendations in this review. Among the most important is a need to identify the minimum quantities of different animal-source foods needed to support the growth and development of children with moderate malnutrition. Furthermore, there is a need to identify appropriate and cost-effective methods for reducing the contents of antinutrients and fibers in plant-based foods. The question of the effect of fat quality on growth and cognitive development in children with moderate malnutrition also needs investigation.

When evaluating which foods are effective in treating moderate malnutrition, weight gain has been the traditional outcome. However, more appropriate outcomes to assess healthy physical development should be included, such as increase in lean body mass and linear growth velocity, and functional outcomes, such as physical activity and psychomotor development.

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Dietary counseling in the management of moderate malnourishment in children

Ann Ashworth and Elaine Ferguson

Abstract

Background. *Dietary counseling is an integral part of treating malnutrition. A first step toward improving the management of moderate malnutrition is to evaluate dietary messages in current programs and assess their adequacy and effectiveness.*

Objectives. *To ascertain current recommendations regarding family foods for the treatment of moderate malnutrition and assess whether these are likely to meet nutritional requirements for rehabilitation; to review the effectiveness of dietary counseling in the management of moderate malnutrition.*

Methods. *Information was requested from 10 United Nations agencies or donors, 20 international non-governmental organizations, 3 pediatric associations, and 6 national programs about the dietary advice they give to caregivers of moderately malnourished children. Adequacy was assessed by comparing dietary recommendations with nutritional requirements. Linear programming was used to identify problem nutrients. A literature search was conducted of studies using family foods for rehabilitating malnourished children.*

Results. *There was a greater emphasis on providing food supplements for rehabilitation than on utilizing family foods. Dietary recommendations were mostly vague and unlikely to be effective. Those developed by the World Health Organization and the Food and Agriculture Organization for well-nourished children may meet nutritional requirements in moderate malnutrition if the recommendations are made more prescriptive. Zinc and vitamin E emerged as possible problem nutrients. Intervention studies in wasted children suggest that counseling caregivers about family foods can achieve good rates of weight gain.*

Conclusions. *Dietary counseling can be effective in managing malnutrition, but it is often weak or absent and should be strengthened. More attention will need to be given to formulating the messages and improving counseling skills.*

Key words: Dietary counseling, dietary management, domiciliary care, effectiveness of treatment, family foods, moderate malnutrition, rehabilitation

Introduction

Background

Moderate malnutrition is common among children in poor countries, and a significant proportion of affected children deteriorate and die if they are left untreated. For example, in a Filipino birth cohort of approximately 3,000 infants who were weighed every 2 months until 2 years of age, on average 11% of those moderately underweight (–2 to –3 weight-for-age z-scores) at any measurement deteriorated to severely underweight within 2 months, and of those who were moderately underweight at 6 months of age and subsequently died, 68% became severely underweight before death [1].

Malnutrition impairs immune function, and malnourished children are prone to frequent infections that are more severe and longer-lasting than those in well-nourished children and may lead to a spiral of ever-worsening nutritional status. In children who are moderately underweight according to the National Center for Health Statistics (NCHS) reference, the risk of death from diarrhea is 5.4 times higher than in well-nourished children; for death from pneumonia, malaria, and measles, the increased risks associated with moderate underweight are 4.0, 4.5, and 3.0, respectively [2]. The risk is attenuated when World

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Health Organization (WHO) growth standards are used, as a smaller weight deficit is required for children to be classified as moderately underweight [3]. It is estimated that 61% of diarrheal deaths, 57% of malaria deaths, and 52% of pneumonia deaths in young children are attributable to coexisting underweight [2].

Despite an obvious need for action, moderate malnutrition has not received the attention it deserves and is rarely seen as a public health priority. The main questions to be addressed in this document are the following:

- What dietary recommendations regarding family foods are currently given to mothers of moderately wasted or moderately stunted children by United Nations agencies, international nongovernmental organizations (NGOs), pediatric associations, or others?
- Are current recommendations regarding family foods likely to meet nutritional requirements for rehabilitation?
- What is the effectiveness of dietary counseling in the management of moderate malnutrition?

Other aspects examined include message design and identification of problem nutrients. The focus is on treatment using family foods. Supplementary foods, manufactured therapeutic foods, and micronutrient powders and pastes are outside the remit of this review and are the subject of a separate article prepared for this Consultation [4].

Context and definitions

The context and definitions were set for the Consultation by WHO. The context includes both food-secure and food-insecure situations in poor countries. Children under 5 years of age are the target group.

Moderate malnutrition includes all children with *moderate wasting,* defined as a weight-for-height between –3 and –2 z-scores of the WHO child growth standard, and all those with *moderate stunting,* defined as a height-for-age between –3 and –2 z-scores of the WHO child growth standard. Most of these children will be *moderately underweight* (weight-for-age between –3 and –2 z-scores).

Methods

Current dietary recommendations regarding family foods for the management of moderate malnutrition were ascertained through correspondence with selected UN and donor agencies, international NGOs, pediatric associations, and ministries of health. A request for information was also posted at ProNut-HIV@healthnet.org, which is a global health information network. In addition, the WHO Secretariat made a request to 210 contacts.

Where sufficient data were available, dietary recommendations were compared with nutritional requirements derived for this Consultation for children with moderate malnutrition gaining weight at a rate of 5 g/kg/day [5]. Linear programming [6, 7] was used to identify "problem nutrients" for a range of dietary patterns and to determine which combination of foods provided the "best-fit solution" in terms of meeting nutritional requirements. A hypothetical child aged 12 to 15 months, 70 cm in length, and weighing 6.7 kg was used to represent a typical case with moderate malnutrition (moderate stunting and moderate wasting).

To ascertain the effectiveness of dietary counseling, a combination of database searches and hand-searching was used for studies published since 1980. These included Medline, Popline, PubMed, BIDS (CAB Abstracts), and the Cochrane Library. Personal contacts were also made for unpublished data. Any strategy for the dietary management of moderate malnutrition should have low case-fatality, support catch-up growth and improve immune function, provide continuing care and support, assess progress, and take action when needed. To assess the effectiveness of dietary counseling, information was therefore particularly sought regarding mortality, rates of weight and length gain, morbidity, immune function, and postrecovery relapse rates.

Results

Current dietary recommendations

Letters were sent to 10 UN agencies and donors, 20 international NGOs, 3 prominent pediatric associations, and 6 large national programs requesting information about the dietary advice they give to mothers and caregivers of moderately malnourished children. One follow-up letter was sent in the event of nonresponse. The respective response rates were 100%, 85%, 100%, and 100%. Up to four programs were sought from agencies and NGOs working in multiple countries, with the aim of capturing the widest range of programs for moderately malnourished children. Respondents were asked to describe their dietary messages and target intakes for energy, protein, and micronutrients as specifically as possible, and to describe how the advice is communicated and by whom, and whether the child's progress is evaluated. Forty-three completed questionnaires were received; the responses are summarized in **table 1**.

Only one program (Bolivia) reported advising a specific treatment (zinc) for stunted, nonwasted children. One program (Niger) reported recommending micronutrient supplements (iron, zinc, and vitamins A and C) for stunted, mildly wasted children. In programs where weight-for-age was used to identify low-weight children, as in growth monitoring and promotion activities, no further screening was usually carried out to differentiate children who were wasted from those who were stunted. Programs using weight-for-age include the Bangladesh National Nutrition Programme (BNNP), the family health program in Brazil (Programa Saúde da Família), CARE, the Dream HIV/AIDS program, the Integrated Child Development Services (ICDS) in India, the Integrated Management of Neonatal and Childhood Illnesses (IMNCI) in India, the Integrated Management of Childhood Illness (IMCI) of WHO, and the Trials of Improved Practices (TIP) of the Food and Agriculture Organization (FAO). In contrast, most NGOs reported specifically selecting wasted children for inclusion into their programs, mostly on the basis of their having 70% to 79% of the median value of the NCHS weight-for-height reference or a mid-upper-arm circumference (MUAC) of 110 to 125 mm (**table 1**).

Pediatric associations (International Pediatric Association, Indian Academy of Pediatrics, Royal College of Paediatrics and Child Health) and some donor agencies (World Bank, US Agency for International Development, UK Department for International Development, Bangladesh Rural Advancement Committee) reported that they do not make dietary recommendations for moderate malnutrition.

About half the respondents reported providing advice about family foods for young child feeding in the general context of health and nutrition education, but few reported emphasizing family foods in rehabilitating malnourished children. Where education sessions were held, the information conveyed was on general issues aimed at preventing malnutrition in siblings or preventing relapse, with a focus on exclusive breastfeeding for 6 months, complementary feeding, hygiene, immunization, bednets, and child care. Thus, the same messages are being given to families regardless of whether their children are well nourished or malnourished, and the dietary needs of malnourished children are thus not addressed.

Respondents working with populations suffering conflict, displacement, and/or food shortage, including the Office of the United Nations High Commissioner for Refugees (UNHCR), the United Nations Children's Fund (UNICEF), the World Food Programme (WFP), and most NGOs, reported informing mothers and caregivers about the use, preparation, and storage of corn–soy blend or other supplementary foods. In some programs, substantial efforts were reported, including cooking demonstrations, to ensure the safe, correct use of supplementary foods, but mostly there was little emphasis on family foods. This is unsurprising, as these agencies work in food-insecure areas where family foods are scarce or nonexistent. Some NGOs reported identifying locally available animal products and different colored fruits and vegetables to enrich corn–soy porridge to improve dietary diversity and quality. Enrichment was often not possible, however, as high prices and exhausted household assets limited families' ability to purchase or barter.

Médecins sans Frontières (MSF) reported providing ready-to-use therapeutic food (RUTF) for treatment of children with moderate malnutrition, and GOAL reported distributing RUTF for moderately malnourished children with medical complications. Some UNHCR and UNICEF programs reported providing RUTF for moderately malnourished children with HIV.

WHO advocates food supplements for moderately wasted children only in emergency situations [8]. Respondents reporting on activities of Africare, IMCI, INMCI (India), FAO, Food for the Hungry, Improving Livelihoods through Increased Food Security (I-Life) (Malawi), and Terre des Hommes stated that no supplementary food was provided in their programs for treatment of moderate malnutrition and that their focus was on family foods. Their approaches are described later.

Overall, recommendations regarding family foods tended to be broad and imprecise. Three food groups (for energy, growth, and protection) with illustrative posters were reported by several respondents as the central focus for their teaching. Individual dietary counseling was rare, and only three respondents (IMNCI-India, FAO, and WHO) reported recommending specific quantities of foods. Portion sizes for specific nutrient-rich foods were absent in all reports except FAO. One respondent with wide experience reported that "the education component in most programs is weak. From my experience to date, what I've observed is that the traditional preach and expect people to practise does not work. The only real successes…have been through practical demonstrations followed by supervised practice sessions…reinforced…through ongoing support until it is adopted into routine household activities."

Dietary messages were communicated by a variety of cadres, ranging from volunteers to nurses and nutritionists, and posters were the most frequently mentioned teaching aid. Although most respondents said they monitored children's weight, fewer than half reported having a target rate of weight gain during rehabilitation. Where reported, the target was typically > 2.5 or > 3 g/kg/day, which is modest.

Programs providing dietary counseling, no supplementary foods

In this section, additional information is provided about the programs of UN agencies, NGOs, and others that rely on family foods alone to meet the nutritional needs of malnourished children, and the extent to which these programs provide specific dietary recommendations. The findings show differences in approach

TABLE 1. Definitions and current treatment practices of moderate malnutrition by selected agencies and national programs

Agency and country	Are stunted, non-wasted children included?	Use NCHS or WHO growth reference	Indicator used for moderate malnutrition					
			W/H < −2 to −3	W/H 70% to < 80%	W/H 70% to < 75%	MUAC 110 to < 115 mm	MUAC 110 to < 120 mm	MUAC 115–125 mm
UN agencies and donors								
FAO (Afghanistan)	Yes Treat same as wasted	N/A No selection						
FAO (Zambia)	Yes Treat same as wasted	N/A No selection						
UNHCR (Djibouti)	No	NCHS		Yes				
UNHCR (Ethiopia)	No	NCHS		Yes				
UNHCR–GTZ (Kenya)	No			Yes				
UNHCR (Tanzania)	Yes	NCHS		Yes				
UNHCR (Uganda)	No	NCHS	Yes					
UNICEF Worldwide	No	NCHS + promote WHO	Yes	Yes			Yes	
UNICEF (Niger)	No	NCHS		Yes				
UNICEF (Uganda)	No	NCHS						Yes
WFP Worldwide	Yes Treat same as wasted	NCHS or WHO if national policy		Yes				Yes
WHO Worldwide	Yes Emphasize animal food if stunted	WHO	Yes					

MUAC 110–125 mm	W/A 60% to 74%	Current practice and focus of emphasis regarding family foods	Specific messages about family foods	Target intake from family foods	Use posters, cards, etc.	Cadre of worker	Monitor weight? Target	Assessed whether counseling is effective
	Yes	Mix of home foods with active feeding	Yes ≥ 5 meals/day Animal food, energy-dense ½–1¼ cups/meal	Yes RDIs	Yes Poster (9 messages) Booklet	Wide-ranging, including AEW, LT	Yes No criteria	No
	Yes	Mix of home foods with active feeding	Yes ≥ 5 meals/day Animal food, energy-dense ½–1¼ cups/meal	Yes RDIs	Yes Booklet	CHP, PE	Yes No criteria	No
		CSB premix RUTF (if HIV+) Little emphasis on family foods	No	None	Yes Cards	RNP	No	No
		CSB premix Little emphasis on family foods	No	None	Yes IYCF cards	NS, OW, CHW	Yes 85% W/H	No
Yes		Usual food + CSB premix Little emphasis on family foods	No	None	Yes Posters	CHW	Yes 85% W/H	No
	Yes	Mixed diet + family ration + CSB premix	No	None	Yes Posters	NW, RS	Yes ≥ 5 g/kg/day	No
		CSB/oil/sugar 3 food groups	No	None	Yes Food group posters	NA, nurses, CHW	Yes No criteria	No
Yes		Usual food + CSB, UNIMIX, BP5, or local mixtures	No	None	Yes IYCF materials	Variable	Yes 85% W/H	No
		CSB/oil/sugar or UNIMIX/oil Little emphasis on family foods	No	None	Yes Cards	Nurses	Yes 85% W/H	No
	Yes	Usual food + CSB/oil/sugar, BP5, or RUTF (if HIV+)	No	None	Yes Variable	MW, HE, CHW, nurses	Yes > 5 g/kg/day	No
	Yes	Mixed diet + CSB or WSB premix	Some Frequent, energy-dense	None	Yes Types vary by country	Variable	Yes Variable criteria	No
	Yes (< −2 SD)	Individual assessment and counseling Mix of home foods with active feeding	Yes Case-specific ≥ 5 meals/day, energy-dense	Yes ¾–1 cup/meal Energy density 0.8–1.0 kcal/g	Yes IMCI cards and HIV/IF card	Variable — 1st- and 2nd-level HW	No	No

TABLE 1. Definitions and current treatment practices of moderate malnutrition by selected agencies and national programs *(continued)*

Agency and country	Are stunted, non-wasted children included?	Use NCHS or WHO growth reference	Indicator used for moderate malnutrition					
			W/H < −2 to −3	W/H 70% to < 80%	W/H 70% to < 75%	MUAC 110 to < 115 mm	MUAC 110 to < 120 mm	MUAC 115–125 mm
International NGOs								
Action Contre la Faim Sudan South Darfur	No	NCHS		Yes			Yes (and/ or W/H)	
Action Contre la Faim–France (Myanmar)	No	NCHS			Yes	Yes (and/ or W/H)		
Action Contre la Faim—USA (East and Central Africa Tajikistan)	No	NCHS		Yes			Yes (and/ or W/H)	
AFRICARE (Guinea)	Yes Treat same as wasted	WHO						
CARE Worldwide	Yes	WHO						
Church World Service (Indonesia)	No	WHO	Yes (< −1.5 SD in some places)					
Concern Worldwide (Democratic Republic of the Congo)	No	NCHS		Yes				
Concern Worldwide (Niger)	No	NCHS		Yes				
Concern Worldwide (South Sudan)	No	NCHS		Yes				
Concern Worldwide (West Darfur)	No	NCHS		Yes				
DREAM 9 African countries; all beneficiaries are HIV+	Yes Treat same as wasted	NCHS	Yes					

MUAC 110–125 mm	W/A 60% to 74%	Current practice and focus of emphasis regarding family foods	Specific messages about family foods	Target intake from family foods	Use posters, cards, etc.	Cadre of worker	Monitor weight? Target	Assessed whether counseling is effective
		CSB food ration + RUF (Supplementary Plumpy) Little emphasis on family foods	No	None	Yes UNICEF materials[a]	HE, HV, SA	Yes ≥ 3 g/kg/day	No
		Premix: rice/ beans/ sugar/oil) 3 food groups Vitamin A, iron, folate supplement	No	None	Yes Posters Booklets	HE	Yes ≥ 2.5 g/kg/day	No
		CSB premix or UNIMIX 3 food groups	No	None	Yes Posters Booklet	HE	Yes > 2 g/kg/day	No
		Family foods (PD/Hearth)	Yes Enriched, frequent, energy-dense	None	Yes Posters Food preparation demonstration	NW, CHW, CV	Yes	Yes
	Yes	Family food + CSB, WSB, oil. cereals, pulses	Yes Home food production	None	Yes Variable	CHW	Yes Variable criteria	No
		Family food + WSB + Sprinkles or vitamin A supplement	No	None	Yes Posters Flipchart		Yes	No
Yes		Family ration + CSB premix Vitamin A, iron, folate supplement Little emphasis on family foods	No	None	Yes UNICEF posters	Nurses, HE, OW, CV	Yes ≥ 2 g/kg/day	No
		Complementary foods + CSB premix	No	None	Yes IYCF posters	CHW, CV, TBA	Yes ≥ 2.5 g/kg/day	No
Yes		Mixed diet + CSB premix	Some Protein, fruit, green leaves	None	Yes	HE, CHW	Yes > 3 g/kg/day	No
Yes (or W/H)		CSB/oil/sugar Little emphasis on family foods	No	None	Yes UNICEF materials[a]	MA, CV, NW, CM, nurses	No	No
	Yes (< −2 SD)	Mixed diet + CSB or other cereal/legume mix + skimmed-milk powder Individual counseling	Yes ≥ 5 meals/day Animal food (egg meat, fish, milk)	None	Yes Booklet	Peers, nurses	Yes No criteria	No

TABLE 1. Definitions and current treatment practices of moderate malnutrition by selected agencies and national programs *(continued)*

			Indicator used for moderate malnutrition					
Agency and country	Are stunted, non-wasted children included?	Use NCHS or WHO growth reference	W/H < −2 to −3	W/H 70% to < 80%	W/H 70% to < 75%	MUAC 110 to < 115 mm	MUAC 110 to < 120 mm	MUAC 115–125 mm
Food for the Hungry Bolivia Democratic Republic of the Congo Kenya	Yes Treat same as wasted	WHO						Yes
GOAL (Ethiopia)	No	N/A (uses MUAC)					Yes	
GOAL (Malawi)	Yes if in PD/Hearth	NCHS		Yes			Yes	
GRET Burkina Faso Madagascar Vietnam	Yes Include well-nourished	N/A No selection						
Helen Keller International (West Africa)	Yes (some)	NCHS		Yes				
International Rescue Committee-–UNHCR (Kenya)	No	NCHS		Yes				
I-LIFE (Malawi)	Yes	NCHS						
Médecins sans Frontières–Spain (Uganda)	No	WHO	Yes				Yes (screen on this, then do W/H)	
Médecins sans Frontières–Suisse Niger Sudan Somalia	No	NCHS or WHO	< −3 SD if use WHO	Yes If use NCHS				
Save the Children—UK 6 African countries Afghanistan	No	NCHS		Yes				

MUAC 110–125 mm	W/A 60% to 74%	Current practice and focus of emphasis regarding family foods	Specific messages about family foods	Target intake from family foods	Use posters, cards, etc.	Cadre of worker	Monitor weight? Target	Assessed whether counseling is effective
	Yes (< −2 SD)	Family ration + CSB/oil, WSB (PD/Hearth)	Yes ≥ 5 meals/day, energy-dense	Yes 600–800 kcal, 20–26 g protein, 4,000 IU vitamin A /meal	Yes IMCI cards	NA, CHW, peers	Yes > 5th centile gain in W/A	Yes
		Mixed diet + Famix/oil Vitamin A supplement	Yes ≥ 3 meals/day enriched porridge	None	Yes Posters Booklets	OW, CHP, nurses	Yes No criteria	No
	Yes (< −2 SD)	CSB (RUTF if HIV+) 6 food groups (PD/Hearth)	Some Frequent, energy-dense	None	Yes Posters	HSA, nurses	Yes >5g/kg/day or > 200 g in 12 days for PD/Hearth	No
		Fortified, locally developed food for 6–23 mo No emphasis on family foods	No	None	Yes Posters Cards Leaflets	N/A	No	No
	Yes (rural Niger)	Mixed diet + CSB/sugar/oil	Yes 3–4 meals Enriched porridge, nutrient-dense	None	Yes	CHW, CV	Yes 85% W/H	No
Yes		Mixed diet + CSB premix (RUTF if complications) Vitamin A, iron, folate supplement Food pyramid	Some Dietary diversity Micronutrients	None	Yes IYCF materials	NW, nutritionists, CHW, nurses	Yes 80% W/H	Yes (not accessible)
	Yes (< −2 SD)	6 food groups (PD/Hearth)	Yes Enriched porridge egg, meat, insects, fats	None	Yes Flipcharts	CHW, CV	Yes 400 g in 2 wk	No
		CSB premix (being replaced by RUF) Vitamin A/iron supplement 3 food groups	No	None	No	HE	Yes > 3 g/kg/day	Yes (not accessible)
		RUTF Little emphasis on family foods	No	None	No	N/A	Yes ≥ 3 g/kg/day	No
Yes		Mixed diet + CSB/sugar/oil	Some Nutrient-rich foods	None	Yes Variable	HCS, NW, CM	Yes No criteria	No

TABLE 1. Definitions and current treatment practices of moderate malnutrition by selected agencies and national programs *(continued)*

Agency and country	Are stunted, non-wasted children included?	Use NCHS or WHO growth reference	Indicator used for moderate malnutrition					
			W/H < −2 to −3	W/H 70% to < 80%	W/H 70% to < 75%	MUAC 110 to < 115 mm	MUAC 110 to < 120 mm	MUAC 115–125 mm
Terre des Hommes (Burkina Faso)	No	NCHS		Yes				
Terre des Hommes Guinea Senegal	No	NCHS + promote WHO		Yes				
Valid Ethiopia Malawi Sudan Zambia	No	NCHS (WHO if national policy)		Yes				
World Vision (Niger)	Yes Emphasize moringa leaf powder with peanut paste + vitamin A 400 RE, iron 10 mg, zinc 3–5 mg, vitamin C			Yes				
National programs								
Bangladesh BNNP	Yes Treat same as wasted	WHO						
Bolivia	Yes Give zinc 10 mg/day for 12 wk	WHO	Yes					
Brazil	Yes Treat same as wasted	WHO						
India ICDS	Yes Treat same as wasted	NCHS						
India IMNCI	Yes Treat same as wasted	NCHS						

AEW, agriculture extension worker; AWW, anganwadi worker; BNNP, Bangladesh National Nutrition Programme; CF, complementary feeding; CHP, community health/nutrition promoter; CHW, community health worker; CM, community mobilizer; CSB, corn–soy blend; CV, community volunteer; DREAM, Drug Resource Enhancement against AIDS and Malnutrition; FAO, Food and Agriculture Organization; GRET, Groupe de Recherche et d'Echanges Technologiques; GTZ, Gesellschaft für Technische Zusammenarbeit; HCS, health center staff; HE, health educator; HIV, human immunodeficiency virus; HSA, health surveillance assistant; HV, home visitor; HW, health worker; ICDS, Integrated Child Development Services; IF, infant feeding; IMCI, Integrated Management of Childhood Illness; IMNCI, Integrated Management of Neonatal and Childhood Illnesses; IYCF, Infant and Young Child Feeding; LT, literacy teacher; MA, medical assistant; MUAC, mid-upper-arm circumference; MW, midwife; N/A, not applicable; NA, nursing assistant;

MUAC 110–125 mm	W/A 60% to 74%	Current practice and focus of emphasis regarding family foods	Specific messages about family foods	Target intake from family foods	Use posters, cards, etc.	Cadre of worker	Monitor weight? Target	Assessed whether counseling is effective
Yes		Individual/group counseling on food preparation and hygiene Vitamin A supplement	Yes Enriched porridge	None	Yes Food preparation demonstration	CHP	Yes 85% W/H or MUAC > 125 mm	No
Yes		3 food groups Vitamin A supplement	Yes Rice flour, soy, fish flour, eggs, pulses, oil	None	Yes Posters	CHP, CV	Yes No criteria	Yes
Yes		Usual food + CSB premix	No	None	Yes Variable	CHW, OW	Yes 85% W/H	No
Yes		CSB premix or UNIMIX 3 food groups Vitamin A supplement	Yes Energy-dense		Yes Cards Posters	Nurses, CHW, NW	Yes > 2.5 g/kg/day 85% W/H	Yes?
	Yes	Premix (rice/lentil/oil/molasses) 5 food groups Vitamin A supplement	Yes Rice, lentils, vegetables, fish, fruit	None	Yes Posters Flipcharts Booklets	CHP, NS, CV	Yes 7–12 mo: 300–400 g/mo 13–24 mo: 150–200 g/mo	Yes
		Family food + RUTF	No	None	Yes Booklet	HCS	Yes No criteria	No
	Yes (< −2 SD)	Family food	Yes 10 steps for CF	None	Yes Variable	CHW	Yes No criteria	No
	Yes	Usual food + cooked meal (rice/lentil/oil/molasses)	No	None	Yes Varies by state	AWW	Yes No criteria	No
	Yes	Family foods Individual assessment and counseling	Yes Case-specific	Yes ¾–2 cups/meal	Yes IMCI mothers' card	AWW, CHW	Yes No criteria	No

NCHS, National Center for Health Statistics; NGO, nongovernmental organization; NS, nutrition supervisor; NW, nutrition worker/assistant; OW, outreach worker/health extension worker; PD/Hearth, Positive Deviance/Hearth approach; PE, peer educator; RDI, recommended daily intake; RE, retinol equivalent; RNP, refugee nutrition promoter; RS, refugee supervisor; RUF, ready-to-use food; RUTF, ready-to-use therapeutic food; SA, social animator; TBA, traditional birth attendant; UNHCR, United Nations High Commissioner for Refugees; W/A, weight-for-age; W/H, weight-for-height; WFP, World Food Programme; WHO, World Health Organization; WSB, wheat–soy blend.

a. The UNICEF booklet includes instructions on how to prepare CSB, breastfeeding, child care (play), and hygiene (personal, environmental).

and in the specificity of the advice. For example, the approach used by WHO relies on individual counseling of mothers and caregivers, whereas NGOs reported disseminating advice through group activities, for example using the Positive Deviance (PD)/Hearth model.

IMCI and IMNCI

IMCI was developed in 1992 by WHO and UNICEF with the aim of reducing deaths from diarrhea, pneumonia, malaria, measles, and malnutrition through prevention or early detection and treatment. IMCI is the conduit through which all community health interventions can be delivered to the child. UNICEF works closely with WHO and partners in implementing IMCI, and especially its community component (C-IMCI). In 2000, the Government of India, in their national adaptation of the IMCI strategy, gave greater attention to neonatal care and named their program IMNCI. Other countries have followed India's lead.

The IMCI/IMNCI algorithm [9] does not specifically identify moderate underweight: it only defines severe cases (< –3 weight-for-age z-scores). Feeding practices are assessed routinely for all children, focusing on the number of breastfeedings per day, other foods given, meal frequency, and how meals are given. For low-weight children, additional questions refer to serving size, who feeds, and whether the child has his or her own plate. If the child is not being fed according to the feeding recommendations (i.e., breastfed on demand, given appropriate foods, adequate servings four or five times per day, responsive feeding), then mothers are counseled. If there is a feeding problem, the child is seen again in 5 days. The dietary recommendations are essentially the same for moderately malnourished and well-nourished children.

The WHO training course on "Infant and young child feeding counselling" provides more specific orientation about " appropriate" foods and "adequate" quantities [10]. The three key messages about "which foods" are that mothers should give animal-source foods daily, a dairy product daily, and a dark-green or yellow vegetable or yellow fruit daily. If meat is not eaten, pulses, nuts, or seeds are to be substituted and eaten with an iron enhancer, such as a food rich in vitamin C. The recommendations for quantities of food to give are as follows: for a child 6 to 8 months of age, gradually increase the quantity of food to approximately one-half cup at each meal; at 9 to 11 months, give approximately one-half cup at each meal; and at 12 to 23 months, give approximately three-quarters to 1 cup at each meal.

WHO child growth program

The WHO training course on child growth assessment, which is linked to implementing the new growth standards, provides a job aid for investigating causes of undernutrition and recommends actions to discuss with a child's mother to address the causes [11]. This job aid is used when a child is moderately wasted, moderately stunted, or moderately underweight. The line of questioning is similar to that followed for IMCI, but in rather more detail, encompassing feeding practices and the child's health and environment (steps 1–6). Preparation for counseling (steps 7 and 8) includes setting goals for two or three actions that a mother can take. Most advice for moderate malnutrition relies on the generic recommendations for well-nourished children. The recommended foods (eight categories) are staple foods, animal-source foods, milk products, green leafy and yellow-colored vegetables, fruits, pulses, oils and fats, and groundnut and other nut or seed pastes. Serving sizes (cups per meal) and the number of meals and snacks are specified for two age groups (6 to 12 months and 1 to 2 years), and energy density is taken into account when determining meal frequency. For example, for children aged 1 to 2 years, the recommendation is for three or four meals daily, with a serving size of three-quarters of a cup at an energy density of 0.8 to 1.0 kcal/g, and one or two snacks between meals. Serving sizes are increased to 1 cup for lower energy densities. For stunted children, the addition of legumes and animal-source foods to meals is encouraged to improve nutrient quality. Actively helping and encouraging the child at mealtimes are also emphasized. For HIV-exposed children, additional animal-source foods and fruits or vegetables twice a day are recommended.

FAO

In Zambia and Afghanistan, the Nutrition Education Group of FAO has been using the Trials of Improved Practices formative research methodology [12] to tailor complementary foods and feeding recommendations to the needs of children aged 6 to 24 months and address moderate malnutrition (E. Muehlhoff, personal communication). The focus is on locally available foods, and two booklets have been developed [13, 14] that are used in conjunction with growth-promotion counseling cards. The booklets are for community nutrition promoters, peer educators, and development workers. The format broadly follows the WHO booklet "Complementary feeding: Family foods for breastfed children" [15]. For example, dietary recommendations for Zambia include eating the staple with a relish containing at least three ingredients from a list of six (fish; beans; green leaves; pounded groundnuts; chicken, eggs, or meat; oil), and eating at least three different kinds of fruit and/or vegetables daily. Portion sizes recommended for the relish, fruit, and vegetable are the amount that can fit into a child's hand. The total meal size recommended is 1/2 to 3/4 cup for children aged 6 to 8 months, 3/4 to 1 cup at 9 to 12 months, and 1 to 1 1/4 cups at 12 to 24 months. Adding a small spoonful of red palm oil to all vegetable relishes is also recommended.

Africare and I-Life

These NGOs reported using the PD/Hearth approach to promote recovery of moderately malnourished children. In this approach, Positive Deviance Inquiry is used to identify feeding, caregiving, and health-seeking behaviors practiced by mothers and caretakers of well-nourished children from poor families and to transfer these positive practices to those in the community with malnourished children [16–18]. The originators were Gretchen and Warren Berggren at the Hôpital Albert Schweitzer, Haiti [19]. PD/Hearth focuses on maximizing existing resources and utilizing local skills and knowledge. Community volunteers help caregivers practice new cooking, feeding, hygiene, or other target behaviors for approximately 2 hours daily during 12 days. Caregivers bring a daily contribution of food and/or cooking materials and practice in groups of about 10 in a local home. The volunteers continue to keep in contact with participants through home visits for two further weeks. PD/Hearth programs often operate in conjunction with growth monitoring, which is used to identify both the malnourished children and positive-deviant families. “Learning by doing” builds caregiver confidence and self-efficacy, and the visible changes in the children’s nutritional status are reported to provide motivation for sustained behavior change [17]. PD/Hearth is implemented mostly by NGOs, and Save the Children (US) was one of the first to use this approach for the rehabilitation of malnourished children, starting in 1990 [20]. PD/Hearth is considered to complement Ministry of Health Essential Nutrition Services, which are largely facility-managed [21], and PD/Hearth is complementing community-based therapeutic care activities in a pilot project in Niger. In this World Vision project, moderately underweight children aged 6 to 36 months who do not qualify for supplementary feeding (i.e., mainly stunted children) are enrolled in a PD/Hearth program where mothers are encouraged to use moringa leaves and peanut flour to enrich children’s meals (S.-S. Dimanche, personal communication).

Africare has implemented PD/Hearth in eight African countries as part of US Agency for International Development (USAID) Title II food security initiatives. These are Burkina Faso, Guinea, Mali, Niger, Sierra Leone, Rwanda, Malawi, and Mozambique. In Guinea, PD/Hearth sessions are led by an exemplary mother chosen by a volunteer community health agent trained by Africare. This model mother then acts as a peer educator whose role includes disseminating messages (usually one theme for each of the 12 sessions), giving demonstrations, and participating in follow-up growth monitoring [22]. She is assisted by volunteer community health agents and Africare field staff. Micronutrient-rich foods are highlighted. Other activities take place in tandem, such as improved agriculture, income generation, and water and sanitation. Qualitative research indicates that PD/Hearth mothers in Guinea have increased awareness about malnutrition and its link with illness and have improved home hygiene and dietary diversity. PD/Hearth children were reported to have improved appetite and weight gain and to be more joyful and lively [22]. Six months after the PD/Hearth sessions, the proportion who were well nourished rose from 0% to 44%.

I-LIFE is a consortium of seven NGOs (Africare, Catholic Relief Services, CARE, Emmanuel International, Save the Children, Salvation Army, and World Vision) working in seven districts of Malawi and receives USAID Title II funding. The program reaches over 60,000 households and uses the PD/Hearth approach for rehabilitating children with mild or moderate malnutrition (A. Kebede, personal communication). Mothers and caregivers are encouraged to prepare an energy-dense, nutrient-enriched maize or sweet potato porridge, for example, by adding groundnut flour and pumpkin leaves, or milk or egg and oil, or soy flour, and to give this with fruit in addition to the usual diet. Mothers and caregivers attend daily in small groups for 12 days at a local house or meeting place where they prepare the enriched porridge. They arrange to bring seasonal ingredients with them for the porridge, with guidance from project staff, and are encouraged to prepare the same porridge at home. The aim is to provide a meal of 600 to 900 kcal, rich in protein and vitamin A.

I-LIFE also promotes irrigation projects and kitchen and communal gardens, with an emphasis on the cultivation, processing, and preservation of high-nutrient indigenous crops through 6,000 Care Groups. The PD/Hearth model fits well within the framework of Care Groups, which aim to help programs go to scale. Care Groups use paid promoters. Households with children under 5 years of age are identified and grouped in blocks of 10 to 15. One volunteer selected from each block is responsible for 10 to 15 households. Volunteers are grouped to form a Care Group who meet every 2 to 4 weeks, and the promoter trains the volunteers about the messages to be communicated to households [23]. Thus, one promoter trains and supervises 10 to 15 volunteers, who in turn are responsible for 10 to 15 households. The concept was pioneered by World Relief in Mozambique, and similar programs have been implemented by Food for the Hungry.

Terre des Hommes reported that their staff in West Africa train community volunteers to demonstrate how to enrich porridges with fish powder, legumes, groundnut paste, green leaves, eggs, and oil. High rates of recovery (> 90%) of moderately wasted children in Benin are reported, with an average time of 4 weeks to attain a well-nourished state (J.-P. Papart, personal communication). Volunteers apply the principles of community-IMCI, including prevention and early treatment of infections.

Extent to which dietary recommendations have been evaluated

In the questionnaire, respondents were asked whether the effectiveness of the dietary counseling component of their program had been evaluated. Most respondents reported having no evaluations, but since few gave prominence to family foods in rehabilitation, this lack is not surprising. Both I-LIFE and Food for the Hungry provided data showing many children moving into the normal range with PD/Hearth or Care Groups. Terre des Hommes reported an average rate of weight gain of approximately 2 g/kg/day for moderately wasted children supervised monthly in Senegal and 4 to 5 g/kg/day with weekly supervision in Benin.

Summary of current dietary recommendations

The dietary recommendations reported by respondents as being given to mothers of moderately wasted or moderately stunted children reflect, at best, the guiding principles for feeding young children and are not necessarily aimed at rehabilitation. For the most part, the recommendations are nonspecific, and this may limit their effectiveness in achieving catch-up growth. There seems, however, to be a general awareness of the need to provide energy-dense, micronutrient-rich foods. The most explicit recommendations among respondents are those developed by FAO in collaboration with the governments of Zambia and Afghanistan, and their recommendations are distinctive in that the portion sizes of micronutrient-rich foods are defined (the amount that fits into a child's hand). No evaluation of the effectiveness of their recommendations in achieving catch-up growth has been undertaken. Apart from two exceptions, the dietary recommendations given for stunted children do not differ from those for wasted children.

Adequacy of current dietary recommendations

The terms of reference envisage that it would be possible to use the information provided by agencies and NGOs to determine the nutritional adequacy of their dietary recommendations for catch-up growth and identify problem nutrients. This is a difficult, if not impossible, task when recommendations are nonspecific. For example, enriching porridge is commendable, but unless one also knows meal frequency, amounts fed, and whether porridge is the sole food, it is difficult to assess dietary adequacy. It was clear, however, that some of the nutritional contents reported for enriched porridges were incorrect. This may be due to faulty or incorrect use of food-composition tables or mathematical error. Reported recommendations also included foods of low micronutrient density, such as grapes and apples.

One commonly used approach for assessing adequacy is to compare a day's menu with nutritional requirements. This can be done with food-composition tables and a hand calculator. As a working example, a menu from Bangladesh was slightly adapted to match the WHO recommendation to eat an animal-source food (in this example egg was chosen), a milk product (milk), green leafy and yellow-colored vegetables (spinach, pumpkin), fruit (pawpaw, guava), pulses (lentils), and oils and fats (vegetable oil) [11]. With this menu, and assuming a nonbreastfed, moderately malnourished child aged 12 to 15 months weighing 6.7 kg, the intake of six nutrients is below the proposed requirements (zinc intake was 41% of that required, calcium 44%, vitamin E 61%, vitamin A 75%, thiamine 87%, and iron 87%). **Annex 1** shows the foods, amounts, and nutrient intakes. There would be no deficit in vitamin A and iron if the menu included 10 g of chicken liver, illustrating that even when one adheres to reasonably tight recommendations, diets can differ in adequacy, and that some diets do not meet requirements even when they conform to WHO recommendations. This can be due to which foods are selected from a list and the amounts eaten.

One solution to this problem is to be very prescriptive. This has been the approach used by some when rehabilitating severely malnourished children at home with family foods [24–27]. For example, Ahmed and colleagues recommended khichuri and halwa as "special foods" and achieved a mean rate of weight gain of 10.4 g/kg/day [27]. Zinc, iron, and multivitamins were provided to support rapid weight gain. The evidence, albeit limited, suggests that mothers are willing to prepare prescribed diets, at least for a limited time, and that children are willing to eat them.

As noted above, even one small manipulation of a menu can improve the adequacy of a diet, and after several iterations, one can design a set of meals that best meet the requirements. This time-consuming task can be eased by linear programming [6, 7]. This technique also allows flexibility: for example, it allows foods to be limited to one or two servings per week, which may be more realistic.

Problem nutrients

Using data from Bangladesh for illustration, the optimum combination of foods to meet the requirements of a moderately malnourished child was identified by linear programming. The procedure is comparable to phase 1 of the four-phase goal programming model described by Ferguson et al. [7], and we have used the food list and portion sizes of Dewey et al. [6] for young children in Bangladesh. Energy and nutrient intakes were calculated primarily from food-composition tables of the World Food Dietary Assessment System [28]. The energy requirement was set at 770 kcal/day (based on a requirement of

115 kcal/kg/day and child weight of 6.7 kg) and the child's nutrient requirements were deduced from the proposed nutrient requirements per 1,000 kcal [5]. All nutrients were considered equally important except for sodium; no attempt was made to meet the sodium requirement, as the food-composition table values were for foods cooked without salt and are thus likely to be underestimates. Selenium, iodine, biotin, vitamin K, vitamin D, and essential fatty acids were omitted from the model because food-composition tables were incomplete for these nutrients and/or unreliable, as composition may vary with the soil content.

Table 2, column 1, shows the foods that were selected for inclusion. We considered that all foods could be eaten daily except chicken liver, for which an upper limit was set at twice per week. We considered that rice would be eaten every day, and therefore we forced rice into the model. We considered that if lentils were selected, they would be eaten with rice at a ratio of 1:1.5, and this linkage was built into the model. Column 2

TABLE 2. Linear programming models: Foods included (column 1) and best food combinations (g/day) to meet requirements for catch-up growth (5 g/kg/day) for a Bangladeshi child aged 12 to 15 months[a]

Food type	Maximum amount in model (g/day)	Breastfed All foods allowed Pattern 1	Not breastfed All foods allowed Pattern 2	Not breastfed No liver Pattern 3	Not breastfed No liver, chicken, or fish Pattern 4	Not breastfed No liver, chicken, fish, or egg Pattern 5	Pattern 5 but with lower requirements[b] for vitamin E and zinc Pattern 6	Lower requirements[b] for vitamin E and zinc; 1 animal food/day Pattern 7
Breastmilk	530	530	—	—	—	—	—	—
Staples								
Rice	195	100	100	101	106	120	100	100
Chapatti	75	37	37	75	75	75	58	68
Semolina	20	0	0	0	3	20	8	0
Rice noodles	70	0	0	0	0	0	0	0
Bread	75	0	0	0	0	0	0	0
Legumes								
Lentils	80	67	67	67	71	80	67	67
Animal foods								
Chicken liver	35	10	10	—	—	—	—	5
Chicken	95	0	0	0	—	—	—	0
Fish	75	34	54	75	—	—	—	6
Egg	50	0	50	50	50	—	—	39
Cow's milk	1,000	0	259	263	252	267	275	255
Roots and tubers								
Potato	125	0	0	0	0	0	0	0
Vegetables								
Pumpkin	130	130	130	130	130	130	130	130
Spinach	40	40	40	40	40	40	40	40
Fruit								
Banana	115	12	0	0	0	0	0	0
Mango	80	0	0	0	0	0	42	6
Orange or orange juice	180	0	0	0	0	0	0	0
Pawpaw	155	107	120	71	143	140	155	155
Guava	25	25	25	25	25	25	12	25
Coconut jelly	20	0	0	0	0	0	0	0
Oils and sugar								
Soy oil	35	0	10	2	5	2	13	8
Gur sugar	20	0	0	0	0	0	0	0

a. Amounts for patterns 1 through 7 are amounts averaged over 7 days.

b. This model used lower requirements for vitamin E (age-specific requirement, 7.6 mg/1,000 kcal) and zinc (requirement assuming no tissue zinc deficit, 5.4 mg/1,000 kcal).

shows the amounts that were considered the maximum that a child aged 12 to 15 months could eat during a day [6]. The remaining columns show the best-fit solutions derived by linear programming for six dietary patterns, ranging from omnivore to an increasingly vegetarian pattern. The amounts represent the average over 7 days, and not all foods are expected to be eaten every day. So, for example, 60 g of a food eaten on 2 days would appear as an average of 17 g/day. Only one of these patterns (pattern 1) is for a breastfed child; we assumed a breastmilk intake equivalent to that of an average healthy child aged 12 to 24 months [29].

Table 3 shows the extent to which the requirements were met and the problem nutrients (i.e., those for which less than 95% of needs were met).

- Pattern 1: breastmilk (530 mL) was forced into this model. "Open choice" of foods. The problem nutrients were vitamin E, calcium, iron, and zinc.
- Pattern 2: the child was assumed to be nonbreastfed. "Open choice" of foods. The problem nutrients were vitamin E and zinc.
- Pattern 3: liver was excluded as an option from pattern 2. The problem nutrients were vitamin E and zinc.
- Pattern 4: liver, chicken, and fish were excluded from pattern 2. The problem nutrients were vitamin E and zinc.
- Pattern 5: liver, chicken, fish, and eggs were excluded from pattern 2. The problem nutrients were vitamin E and zinc.

Pattern 5 was then rerun but using lower estimates for the requirements of vitamin E and zinc. For vitamin E we used the age-specific requirement (7.6 mg/1,000 kcal instead of 11.5 mg/1,000 kcal), and for zinc we

TABLE 3. Percentage of requirements met by the seven models for a weight gain of 5 g/kg/day in a Bangladeshi child aged 12 to 15 months (weight, 6.7 kg; energy requirement, 770 kcal/day)

Nutrient	Requirement/1,000 kcal	Breastfed All foods allowed Pattern 1	Not breastfed All foods allowed Pattern 2	Not breastfed No liver Pattern 3	Not breastfed No liver, chicken, or fish Pattern 4	Not breastfed No liver, chicken, fish, or egg Pattern 5	Pattern 5 but with lower requirements for vitamin E and zinc[a] Pattern 6	Lower requirements for vitamin E and zinc[a]; 1 animal food/day Pattern 7
		% of requirements met						
Protein	24 g	145	210	229	173	157	137	171
Vitamin A	960 µg	389	399	194	271	255	294	356
Vitamin E	11.5 mg	**60**	**75**	**69**	**63**	**51**	97	100
Vitamin C	75 mg	258	238	183	258	255	245	273
Thiamine	600 µg	109	122	122	100	108	100	102
Riboflavin	800 µg	123	206	169	163	128	126	176
Niacin	8.5 mg	180	216	234	187	181	159	191
Vitamin B_6	800 µg	100	119	125	118	122	111	116
Folate	220 µg	212	210	170	186	185	172	198
Vitamin B_{12}	1 µg	895	1,094	434	203	138	143	564
Pantothenic acid	2.7 mg	165	203	187	169	146	135	175
Calcium	600 mg	**61**	100	100	100	100	100	100
Phosphorus	600 mg	100	164	185	147	140	125	145
Magnesium	200 mg	97	108	126	121	124	111	117
Potassium	1,400 mg	144	162	158	152	152	150	154
Sodium	550 mg	35	63	64	56	44	45	55
Iron	9 mg	**89**	100	100	100	99	**86**	100
Zinc	13 mg	**38**	**49**	**51**	**49**	**48**	100	116
Copper	680 µg	125	100	108	110	121	105	108
Manganese	1.2 mg	535	192	239	245	266	219	231
Phytate:zinc < 15		Yes	Yes	Yes	Yes	15.7	Yes	Yes
Problem nutrients (< 95% of needs met)		Vitamin E, calcium, iron, zinc	Vitamin E, zinc	Vitamin E, zinc	Vitamin E, zinc	Vitamin E, zinc	Iron	None

Boldface numbers denote problem nutrients (i.e. less than 95% of requirement is met)

a. This model used lower requirements for vitamin E (age-specific requirement, 7.6 mg/1,000 kcal) and zinc (requirement assuming no tissue zinc deficit, 5.4 mg/1,000 kcal).

TABLE 4. Studies of malnourished children treated at home by dietary counseling (no food provided)

				Rehabilitation				Follow-up		
Authors Country Year published [ref]	Type of study Urban/rural	Age Admission criteria or severity of malnutrition Implementer	No. of children studied Focus of counseling	Duration of intervention Micronutrient supplement	CFR (%) Relapse (%) Morbidity	Weight gain or progress	Cost/child	Follow-up	Later mortality (%)	Later relapse (%)
Husaini et al. Indonesia 1986 [31]	Observational	6–36 mo Grade III (Gomez) or edema but not severely ill OTP nutrition clinic	108 Skimmed milk	3 mo 5 counseling visits at home No micronutrients given	CFR 16.6 Relapse NR Morbidity NR	In a subset (n = 49): Mean weight gain 12 g/day (1.7 g/kg/day)* At entry 12% were ≥ 80% W/H After 6 mo 84% were ≥ 80% W/H	NR	Not done	NR	NR
Castillo et al. Chile 1983 [32]	Observational Urban	< 12 mo W/A < –2 SD to > –3 SD OTP health centers and a nutrition clinic	294 a) 250 at 10 health centers b) 44 at nutrition clinic a) No details b) Individual counseling	NR No micronutrients given	CFR NR Relapse NR Morbidity NR	3 mo later in the subset (n = 274) of those < –2 SD and > –3 SD W/A: a) 31% reached –1 SD W/A b) 73% reached –1 SD W/A	NR	Not done	NR	NR
Glatthaar et al. South Africa 1986 [33]	RCT Urban slum	7–36 mo Mean age 18 mo Mostly moderately malnourished cases ≤ 72% W/A or ≤ 79% W/A + edema or W/H < 95% OTP hospital	140 a) 65 intervention b) 75 control 5–6 meals/day Energy-dense porridge Staple + low cost protein foods + vegetables	3 mo a) 6 counseling visits at home b) No visits (controls) No micronutrients given	CFR: a) 11.7 b) 5.4 Relapse NR Morbidity: high incidence of diarrhea	Mean W/H (NCHS): At entry a) 81%, b) 82% After 3 mo a) 88%, b) 87% Mean H/A (NCHS): At entry a) 90%, b) 90% After 3 mo a) 89%, b) 89%	NR	9 mo later: W/H a) 91%, b) 91% H/A a) 89%, b) 89%	a) 0 b) 0	NR
Fernandez-Concha et al. Peru 1991 [34]	Observational Urban slum	Mean age 18 mo Grades II and III (Gomez) 87% were moderately malnourished Mean W/H ~ 88%	54 ≥ 4 meals/day Breastfeed + energy-dense, protein-rich meals + fruit and vegetables	12 mo Home visits by doctor and nurse in wk 1, then weekly clinic visits No micronutrients given	CFR 0 Relapse 0 Morbidity NR	% W/A: At entry grade II 87%, grade III 13% After 3 mo grade II 47%, grade III 2% After 12 mo grade II 19%, grade III 0%	US$21/child	Not done	NR	NR

continued

TABLE 4. Studies of malnourished children treated at home by dietary counseling (no food provided) *(continued)*

Authors Country Year published [ref]	Type of study Urban/ rural	Age Admission criteria or severity of malnutrition Implementer	No. of children studied Focus of counseling	Rehabilitation				Follow-up		
				Duration of intervention Micronutrient supplement	CFR (%) Relapse (%) Morbidity	Weight gain or progress	Cost/child	Follow-up	Later mortality (%)	Later relapse (%)
Bredow and Jackson Jamaica 1994 [35]	Observational Rural	< 3 yr Grades II and III (Gomez) or edema Mean age 16 mo for grade II Health center	36 (rural clinic) Breastfeed + high-energy milk + family food	Mean 5.6 mo Mean of 6 clinic visits: weekly if ill, otherwise monthly Iron, multivitamins, and folic acid given for 1 mo	CFR 2.7 Relapse 0 Morbidity NR	Mean weight gain 1.4 g/kg/day*if grade II At entry mean W/A 62%, mean H/A 89% 5.6 mo later mean W/A 73%, mean H/A 88%	US$14 for medicines	NR	NR	NR
Khanum et al. Bangladesh 1994 [24–26]	RCT-S Urban poor	12–59 mo < 60% W/H and/or edema Mean W/A 48% Mean W/H 67% Mean H/A 84% 98% had edema Mean age 25 mo Save the Children nutrition rehabilitation unit	437 a) 173 inpatient b) 134 day care c) 130 1wk day care and then at home 3 energy-dense, protein-rich meals with vegetables + 2 snacks + 4 milk drinks	Until ≥ 80% W/H and edema free Mean no. of days taken:- a) inpatient 18 b) day care 23 c) domiciliary 35 Iron and multivitamins given to take home Child given own bowl to take home	CFR: a) 3.5 b) 5.0 c) 3.5 Relapse: a) 0 b) 0 c) 0 Morbidity: high incidence of diarrhea, ARI, skin infections	Mean weight gain during recovery to 80% W/H (g/kg/day): a) inpatient 11 b) day care 6 c) domiciliary 4 (all are underestimates as these include resolution of edema) Mean height gain during recovery to 80% W/H (cm): a) inpatient 0.6 b) day care 0.2 c) domiciliary 0.7	Cost to center to rehabilitate a)US$156 b)US$59 c)US$29	12 mo later: Mean W/H a) 91%, b) 91%, c) 91% Mean H/A a) 84%, b) 84%, c) 84%	a) 3.4 b) 1.5 c) 1.5	a)1.2 b) 0.7 c) 0
Ahmed et al. Bangladesh 2002 [27]	RCT Urban poor	6–60 mo < −3 SD W/H and/or edema	225 a) inpatient b) home visits c) clinic visits (75/group) ≥ 6 meals/day Energy-dense meals (milk suji, khichuri, halwa)	Until ≥ 80% W/H and edema free Median no. of days taken: a) 17 b) 20 c) 37 Iron, zinc, folic acid, and multivitamins given	CFR: a) 1.3 b) 0 c) 0 Relapse NR Morbidity NR	Mean weight gain (g/kg/day): a) 11.9 b) 9.9 c) 7.5 (a) vs. (b) not significantly different	Cost to center to rehabilitate a)US$76 b)US$21 c)US$22	NR	NR	NR

Schroeder et al. Vietnam 2002 [20, 36, 37]	RCT Rural	5–15 mo W/A < −2 SD to > −3 SD (most were stunted) Save the Children integrated nutrition program Hearth model	35 (subset) a) 16 intervention b) 19 control Energy-dense meals	12-day sessions No micronutrients given	CFR 0 Relapse NR Morbidity: ARI reduced in intervention group	Difference from baseline in mean WAZ: After 4 mo a) −0.05, b) −0.25 Difference from baseline in mean HAZ: after 4 mo a) −0.20, b) −0.50	NR	8 mo later: Change in mean WAZ a) −0.11, b) −0.24 Mean H/A a) −0.10, b) −0.52	NR	NR
Roy et al. Bangladesh 2005[30] and personal communication	RCT Urban poor	6–24 mo W/A 61%–75% Community nutrition centers a) and b) used graduate health assistants c) used center staff	282 a) Twice-weekly group education b) Twice-weekly education + food c) Fortnightly education by BINP ≥ 5 meals/day Energy-dense meals (khichuri)	3 mo No micronutrients given	CFR NR Relapse NR Morbidity: high incidence of diarrhea and fever	Mean W/A: At entry a) −2.80, b) −2.90, c) −2.90 After 3 mo a) −2.51, b) −2.36, c) −2.79 Mean H/A: At entry a) −2.39, b) −2.48, c) −2.15 After 3 mo a) −2.55, b) −2.16, c)−2.34	NR	3 mo later: Mean W/A, a) −2.41, b) −2.15, c) −2.84 Mean H/A a) −2.43, b) −2.05, c) −2.46	NR	NR
Roy et al. Bangladesh personal communication, 2008	RCT Urban poor	6–24 mo W/A 61%–75% Community nutrition centers	579 a) Twice-weekly group education for 6 mo b) Weekly group education for 3 mo and then fortnightly for 3 mo ≥ 5 meals/day, energy-dense (khichuri)	6 mo No micronutrients given	CFR 0 Relapse NR Morbidity: high incidence of fever and ARI in both groups	Mean W/A: At entry a) −2.72, b) −2.78 After 3 mo a)−2.45, b) −2.50 Mean H/A: At entry a) −2.66, b) −2.71 After 3 mo a) −2.77, b) −2.76	NR	9 mo later: Mean W/A a) −2.38, b) −2.37 Mean H/A a) −2.80, b) −2.80	NR	NR

* estimated from authors' data

ARI, acute respiratory infection; BINP, Bangladesh Integrated Nutrition Progamme; CFR, case fatality rate; H/A, height-for-age; HAZ, height-for-age z-score; NCHS, National Center for Health Statistics; NR, not reported; OTP, outpatient; RCT, randomized, controlled trial; RCT-S, randomized, controlled trial with systematic allocation; W/A, weight-for-age; WAZ, weight-for-age z-score; W/H, weight-for-height took the figure that assumes no tissue deficit (5.4 mg/1,000 kcal instead of 13 mg/1,000 kcal). When these lower estimates were used, vitamin E and zinc were no longer problem nutrients, but iron had 86% adequacy (pattern 6), as there was a trade-off between meeting the requirements for vitamin E and meeting those for iron. There were no problem nutrients in pattern 7 when one animal food (liver, chicken, fish, or egg) was allowed daily.

It may seem surprising that pattern 5, with no liver, chicken, fish, or eggs, was no more problematic in meeting requirements than patterns including these foods (patterns 2, 3, and 4), but even with an "open choice," as in pattern 2, linear programming chose substantial amounts of milk, lentils, pumpkin, spinach, pawpaw, and guava, all of which featured in pattern 5. Of note is that three of these foods (pumpkin, spinach, and guava) were at the amounts considered as the maximum that a child of this age would eat. Interestingly, the food combinations generated by linear programming are very similar to those successfully used in Bangladesh by Khanum et al. and Ahmed et al. for rehabilitating severely malnourished children [24–27].

When pattern 7 was rerun excluding mango, orange, and pawpaw to simulate seasonal shortage, different quantities of foods were selected in the best-fit solution, but overall adequacy was maintained (data not shown). When the analyses were rerun using foods and amounts from the Ghana database [6], the findings were similar, despite the use of very different staples and other foods.

Refining dietary recommendations

Can these best-fit solutions help us refine dietary recommendations to meet the needs of moderately malnourished children? As indicated earlier, adequacy varies according to which foods are chosen from lists of recommended foods. It is thus important to know if the recommendations are adequate for a worst-case scenario, e.g., if a mother chooses cabbage rather than spinach, or cassava rather than rice. Testing worst-case scenarios can be helpful in refining lists of recommended foods so that requirements are met for all scenarios. More prescriptive dietary recommendations usually emerge from such testing. Best-fit solutions must also be able to be assembled into recognizable meals, so considerable care is needed when using this methodology. Best-fit solutions must also be tested for different age groups. Dietary recommendations must be affordable, sustainable, culturally appropriate, and simple to convey to mothers and caregivers, and thus it is important to test the suitability of best-fit solutions through household trials of behavior change and to modify the recommendations if needed. In some situations, one may need to consider whether costs can be reduced by providing part of the micronutrient requirements as a supplement.

The results presented above are intended as examples of linear programming and cannot be extrapolated. In all settings, nutritional adequacy should be checked. In some settings, sufficient information may be available to make linear programming possible, and in these cases linear programming can help optimize the use of local foods in meeting nutritional requirements.

Effectiveness of dietary counseling in the management of moderate malnutrition

Studies were sought in which mothers or caregivers of moderately malnourished children were counseled about rehabilitating their children at home with family foods. Only two studies were located in which moderately malnourished children were specifically targeted; both of these were in Bangladesh [30] (and S.K. Roy et al., personal communication). Studies were therefore also sought in which severely malnourished children were rehabilitated at home with family foods until they reached at least 80% weight-for-height or −2 z-scores. The justification for their inclusion is that these children pass through a phase of moderate malnutrition during their recovery.

Ten studies were examined; **table 4** summarizes the data [20, 24-27, 30–37]. Where possible, the table identifies the nutritional status of the children at recruitment, the type of intervention and the implementer, and the outcomes (case-fatality, weight gain, morbidity, progress during follow-up, and relapse). Immune function was not an outcome in any of the studies. Only sketchy information is provided about the intervention and its delivery for several studies, and some lack methodological rigor. Few authors report rates of weight gain, and therefore where possible estimates were made from other data presented, but with consequent risk of error. Sample sizes are small in some studies.

The studies indicate varying success, with average weight gains ranging from around 1.5 to 10 g/kg/day. Those with slow rates of weight gain appear to have a high proportion of stunted subjects, for whom rapid rates of weight gain would not be expected. Five studies report morbidity, which was high in four studies. Two studies [31–32] provide little information about the dietary counseling, and eight, which describe delivery of the intervention and report the findings in some detail, are described below.

South African study of Glatthaar et al. [33]

The subjects were hospital outpatients with moderate underweight, mean age 18 months, many from urban squatter settlements north of Pretoria, who were rehabilitated at home through dietary counseling. Their illnesses were treated, and they were randomized to dietary intervention or control groups. Dietary modifications that were promoted were increased feeding frequency (five or six meals and snacks), increased energy density of porridge (by making it thicker and adding fat, oil, or sugar), addition of protein-rich foods (e.g., milk to porridge, and legumes, peanut butter, chicken, offal, or eggs to the staple), and increased consumption of vegetables. Nurses fluent in the local language delivered the counseling at six home visits, which included demonstrations and supervised practice. The aim was an energy intake of 120 kcal/kg/day and a protein intake of 3 or 4 g/kg/day with an emphasis on "practical measures, rather than abstract concepts." The first visit lasted 1.75 hours on average, and subsequent visits lasted 30 minutes, with intervals of about 2 weeks between visits. The intervened children (*n* = 65) improved from 81% to 88% weight-for-length during 3 months, with an estimated rate of weight gain of about 1.6 g/kg/day, but the control children (*n* = 75) also improved to a similar extent. Thus the dietary counseling per se did not have a significant role in the children's recovery, and the authors suggest that the initial treatment of infections may, at least in part, have played an important role. A high incidence of diarrhea in the study population during the rehabilitation period may have limited the rate of catch-up growth.

Peru study of Fernandez-Concha et al. [34]

The subjects resided in a periurban shanty town of Lima, and most of the 54 subjects were moderately underweight. Dietary counseling was provided by a physician, first at home and then at a clinic. A nurse also helped with counseling at the clinic. Mothers received seven basic messages about breastfeeding, good complementary feeding, meal frequency, handwashing, birth spacing, and prenatal nutrition. After 3 months, approximately 50% of the children had moved into the mildly malnourished or well-nourished category.

Jamaica study of Bredow et al. [35]

In this study, highly prescriptive dietary advice was provided by health aides to mothers of malnourished children at a clinic. The advice for catch-up growth was to prepare a high-energy milk (150 kcal/kg/day) that could be taken as a drink or made into porridge. Other family foods were allowed, but only in addition to the milk. The milk was prepared from skimmed-milk powder to which was added margarine or coconut oil. The amounts of milk powder and margarine (in soupspoonfuls) were calculated for each child according to weight, and the mothers were given explicit instructions. Malnourished children (*n* = 25, Gomez grade I and II) with a mean weight-for-age of 68% improved to 77% over 5.6 months, equivalent to a weight gain (estimated) of 1.4 g/kg/day. Most were moderately stunted and mildly wasted.

Bangladesh study of Khanum et al. [24–26]

This study was implemented by the Children's Nutrition Unit, Dhaka, which served as a referral center for severe malnutrition, with about 1,300 admissions per year. It was largely financed by Save the Children (UK). The admission criteria were weight-for-height < 60% and/or edema. In 1990, treatment at home with family foods was introduced and a cost-effectiveness trial was undertaken to compare inpatient care (*n* = 173), day care (*n* = 134), and domiciliary care after 1 week of day care (*n* = 130). In the domiciliary group, home visits were conducted weekly for 1 month or until edema disappeared, and then fortnightly. Multivitamins and iron were provided for the domiciliary group, but no food. None of the groups received zinc. While at the unit, caregivers received 20 minutes of structured instruction each day on topics relevant to child feeding, disease prevention, and family planning. They also participated in cooking demonstrations and practiced meal preparation. The domiciliary group received additional instruction during their week at the Unit, particularly on what to feed, how much, and how often. The foods recommended for daily consumption at home were one bowl of rice pudding; one bowl of rice, lentils, and vegetables; one bowl of rice and lentils or potato and pumpkin with meat or fish if affordable and cooked in oil; 3 cups of milk; and two snacks (chapatti, dhal, banana, or fruit). The bowl (340 g capacity) and cup (180 mL) used in the practice sessions were given for the child to take home. Marks were put on the containers to indicate the amount to give, according to the child's weight.

The domiciliary group gained weight more slowly than the other two groups, but the cost of their care was about one-fifth of the cost of inpatient care. The rate of weight gain during the period approximating moderate malnutrition averaged 4 to 5 g/kg/day. The children gained in stature but not in height-for-age. Infections were reported in 38% of study weeks, and infection, poor appetite, and nonadherence to dietary advice adversely affected weight gain at home. Financial constraint was the main reason for not adhering to the feeding advice. The authors concluded that better weight gains and improved resistance to infection might have been achieved if the domiciliary group had continued to receive potassium and magnesium and if all children had been given zinc.

The home visitors were very motivated and were carefully selected and trained. They gave feasible advice, were sympathetic and supportive rather than castigating, and involved fathers and grandparents in decision-making. They were trained to weigh and examine children and differentiate minor from major illnesses so they could refer back when necessary.

Parents preferred domiciliary care despite their poverty and the substantially higher parental costs. Following the trial, domiciliary care became a routine service, and parents were offered a choice of inpatient, day care, or domiciliary care. Mothers of recovered children also acted as informal peer counselors to give help and encouragement to other mothers rehabilitating their children at home.

Bangladesh study of Ahmed et al. [27]

Severely malnourished children admitted to the Dhaka Hospital of the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B) were randomized after 7 days to domiciliary rehabilitation with home visits by health workers, domiciliary rehabilitation with clinic visits, or continued inpatient care. No deaths occurred in the domiciliary groups, and the median time taken to reach 80% weight-for-height was 20 days with home visits, 37 days for the clinic group, and 17 days for the inpatient group. The rate of weight gain in the home-visited group averaged 10 g/kg/day, compared with 7.5 g/kg/day for clinic patients and 12 g/kg/day for inpatients. The cost of domiciliary care was about one-third the cost of inpatient care.

No food was distributed. Considerable effort was made to identify specific high-energy, high-protein, low-cost foods to promote for home feeding. These were khichuri and halwa, and mothers practiced preparing these foods before going home. Zinc syrup, folic acid, multivitamins, and iron supplements were provided. The Dhaka Hospital has a well-established health and nutrition education program for mothers, which includes many aspects of child care. (n.b., Dispersible zinc acetate tablets that provide 20 mg zinc/day have now become available, so these have replaced zinc syrup).

This study shows that rapid rates of weight gain (10 g/kg/day) can be achieved at home with family foods and a micronutrient supplement. The children improved from a mean of −3.2 to −1.9 weight-for-height z-scores in 20 days. Since 8 of these 20 days included the stabilization period when no weight gain is expected, the actual rate of weight gain at home can be expected to have been higher than 10 g/kg/day.

Vietnam study of Schroeder et al. [20, 36, 37]

In the 1990s, Save the Children (US) developed a PD/Hearth component as part of an integrated nutrition program in Vietnam. Community health volunteers identified malnourished children (< −2 weight-for-age z-scores) through regular screening and enrolled them in the program, which also included deworming and supplementation with vitamin A and iron. Children who did not gain adequate weight during the 12-day PD/Hearth sessions were invited to attend a second cycle. If they still did not gain sufficiently, the families were provided with revolving loans of laying hens (or other sources of income) [38]. These families were required to give their malnourished children at least five eggs each week. In the evaluation study, six communes were randomly selected to participate in the program and were matched with six communes to serve as controls. In each group, 120 children were randomly selected from hamlets with the highest rates of malnutrition. Moderately underweight children ($n = 35$) were identified and followed prospectively. There were 19 children in the control area and 16 in the intervention area. Both groups deteriorated in height-for-age and weight-for-age following recruitment, but the intervened group deteriorated significantly less than controls. Despite a significant benefit of the PD/Hearth program, it cannot be considered successful, as the children's nutritional status deteriorated. This may have been due to lack of catch-up in height, since the children were underweight primarily because they were stunted, and failure to catch up in height would have a direct effect on weight-for-age.

The program achieved integration of the volunteers' activities with primary health services and with vertical programs (e.g., expanded immunization, control of acute respiratory infection and diarrheal disease, and family planning) [38].

Bangladesh studies of Roy et al. [30]

These two studies specifically recruited moderately underweight children (weight-for-age 61% to 75% of NCHS reference).

In the first study [30], mothers of 282 children aged 6 to 24 months attending growth-monitoring nutrition centers were randomized to one of three groups. One group received nutrition education twice weekly for 3 months, and the second group received the same education intervention plus a wheat–pulse–molasses–oil food supplement of 300 kcal and 8 to 9 g of protein/day. The comparison group received standard nutrition-center services with no supplementary food. Graduate-level health assistants delivered the education intervention, which focused on the preparation of khichuri (rice, lentils, potato, green leaves, oil, and egg, meat, or fish). The preparation of khichuri was demonstrated and practiced, and the nutritional contents of food ingredients were described. Other family foods mixed with oil were also encouraged. The mothers were advised to cook the whole amount of khichuri (650 g) in the morning and feed it in five or six servings during the day, and to give children their own bowls. The two intervention groups improved in weight-for-age compared with the comparison group ($p < .001$ in each case). There was no significant difference, however, between the two intervention groups, implying that the food supplement provided no added benefit. Children in the intervention groups had significantly more diarrhea than comparison children, and diarrhea had a negative effect on weight gain. Whether the diarrhea could be due to prolonged storage of the khichuri is not discussed.

Although the effect of the intervention on weight-for-age was statistically significant, the rate of weight gain was slow (estimated at 1 to 2 g/kg/day), and only around 40% of the children moved into the mildly malnourished or well-nourished category. However, the children were stunted rather than wasted. Length gain was significantly greater for children receiving the food supplement (3.5 cm vs. 2.3 cm for unsupplemented children), and their length-for-age improved. Unsupplemented children deteriorated in length-for-age (S.K. Roy, personal communication).

In the second study, an intensive education regimen (twice weekly for 6 months, *n* = 292) was compared with a less frequent education regimen (once weekly for 3 months and then fortnightly for a further 3 months, *n* = 287) (S.K. Roy, personal communication). Four subdistricts (upazilas) were selected, and from each of these 30 nutrition centers were selected, which were randomized into two groups. Groups of six to eight mothers were counseled by health assistants about child feeding, and they were encouraged to feed energy-dense, nutrient-dense foods. Oil, eggs, vegetables, and fruits were emphasized, as was the need for the child to have his or her own bowl. The preparation of khichuri was demonstrated and practiced, and the nutritional contents of food ingredients were described. The children in both groups gained an average of 1.3 kg during 6 months of intervention, giving a rate of weight gain of 1 g/kg/day. Approximately 40% of the children moved into the mildly malnourished or well-nourished category by the end of 6 months. Again, the children were stunted rather than wasted, and they deteriorated in length-for-age during the 6-month intervention.

Neither of these studies can be considered a success in terms of catch-up growth. Behavior change was reported in both studies, but this was insufficient to achieve catch-up in length.

Conclusions regarding the effectiveness of dietary counseling

Published data regarding the effectiveness of dietary counseling to mothers of moderately malnourished children are very limited. In the studies reviewed, rates of weight gain tended to be slow, with estimates of 1 to 2 g/kg/day. Recurrent infections, associated with poor living conditions and high pathogen exposure, were reported in four of the five studies with morbidity data, and poor appetite during illness may have limited growth. Most of the data, however, pertain to stunted rather than wasted children, and relatively slow rates of weight gain can be expected for stunted children. In Bangladesh, where the prevalence of low birthweight in poor families is very high, it is likely that many of the stunted children would have been growth retarded *in utero*.

For studies with predominantly wasted children, weight gain was more rapid, and an average rate of 10 g/kg/day was achieved with family foods and zinc/iron/multivitamin supplements in Bangladesh. Where zinc was not provided, the average rate of weight gain was more modest (4 to 5 g/kg/day). Common elements included frequent meals (at least five daily), food mixtures that families could afford, and opportunities to learn through supervised practice.

Discussion

Advocacy is important for action, but advocacy remains weak for improved complementary feeding and for utilizing family foods for catch-up growth, especially when compared with advocacy for breastfeeding [39]. As one authoritative respondent reported, "We are facing a capacity crisis in nutrition as nutrition programmes are not given priority at policy and implementation level. There is negligible emphasis given to preventive programmes. Donors prefer quick fix solutions favouring micronutrient supplementation and ready-to-use foods, spreads and sprinkles . . . instead of addressing the root causes of undernutrition."

It is widely accepted that the quality of nutrition counseling is often poor, whether it be in growth monitoring and promotion programs, for improving complementary feeding, or for community-based rehabilitation [40, 41]. Evidence is accumulating, however, from both malnutrition rehabilitative and preventive programs, that dietary counseling can be effective when done well and can achieve gains in length and weight [27, 42-45] In successful programs, frequent, regular exposure to a few simple, uniform, age-appropriate messages, together with an opportunity for interaction between caregiver and counselor, has been found to be important. Achieving a balance between delivering uniform messages and negotiating compromises to fit, for example, competing demands on mothers' time, requires significant skill and insight, but nutrition counseling is often left to minimally trained personnel or volunteers with poor knowledge and communication skills.

Over the years, there has been a shift in emphasis in young child feeding from protein quantity and quality to energy density, and more recently to micronutrient density, and these shifts have been reflected in programs, research agendas, and donor funding. This shift in emphasis, however, should not be construed as meaning that the earlier foci of emphasis were misplaced, since all these aspects are relevant when considering rehabilitation of malnourished children. The important influence of the home environment on growth has also been increasingly recognized, with attention being given to feeding frequency, active feeding, hygiene, and management of illness, among others. These aspects, too, are relevant when rehabilitation of malnourished children is considered, but with so many factors for consideration, it can be difficult to decide on a few priority messages.

Formative research is an integral part of the design and development of nutrition counseling interventions, so that the social context and the resources available at home (food, fuel, time, etc.) are taken into account. The aim is to provide feasible, memorable messages that motivate behavior change. Lack of formative research can lead to recommendations that are unrealistic or that conflict with cultural beliefs. Even when efforts are made to take cultural beliefs into account when designing nutrition interventions, feeding messages can face resistance and be ignored because of other constraints, as was reported from China [46]. Nonadherence to counseling messages is commonly associated with lack of resources and incompatibility with demands on mothers' time, which may include time away from the home for paid employment or agricultural work. Pelto and colleagues [47] list four principles for formative research:

» Obtain knowledge about current feeding behaviors;
» Obtain an understanding about key context conditions and determinants of current behaviors;
» Work with communities to design interventions that are responsive to the context and local values;
» Build on the principles and strategies of individual, family, and community behavior change.

The feasibility of rehabilitating malnourished children with family foods depends on the social context and the family's access to food. It is clearly not feasible to rely on family foods in food-insecure humanitarian relief settings. Some contexts, however, have the potential to access family foods, for example, by establishing agricultural plots or kitchen gardens, but this potential may be suppressed by the provision of supplementary and therapeutic foods.

Ideally the health-system infrastructure should integrate both prevention and treatment of malnutrition, and it may be possible to take local or national complementary feeding guidelines (aimed at malnutrition prevention) and make minimal adjustments so that they support catch-up growth. The recommendations for a malnourished child may thus become somewhat more prescriptive than those for a healthy child, such as "give two cups of milk" rather than "give a dairy product" or "give half a cup of pawpaw" rather than "give an orange-colored fruit." Malnourished children rehabilitated at home need to be monitored, either through home visits or at a clinic. Clinics should play a key role in home rehabilitation, as they are the most sustainable delivery channels. The IMCI strategy envisages them as pivotal in preventing malnutrition, case-finding, referral, and monitoring. With appropriate training and resources, clinic staff could deliver home-based rehabilitation. The NGO sector can also be pivotal in scaling up. For example, the Bangladesh Rural Advancement Committee (BRAC), which started in response to the plight of thousands of refugees after Bangladesh's War of Independence, is now a global leader in primary health care and social development, reaching more than 110 million people in Asia and Africa. The joint UNICEF and ICDS Dular project in Bihar and Jharkhand and the Anchal Se Angan Tak project in Rajasthan also reach very large populations through village workers. One of the challenges in going to scale is maintaining a high quality of implementation.

In several of the reports and studies examined, recovery was slow when compared with the efforts apparently exerted, and there is a need for a better understanding of the reasons for these modest results. Better-designed studies at sufficient scale are needed that will allow in-depth analysis. These should include process evaluation and better-defined outcomes. Adherence, rates of weight and length gain, immune function, and morbidity should be measured, and the data from wasted children should be analyzed separately from those from nonwasted, stunted children. Robust methodologies are required, with control or comparison groups.

Wasted children will gain weight rapidly if fed appropriate amounts of family foods, and it is rewarding and motivating for families, neighbors, and health workers to see this striking transformation. Consideration should therefore be given to formulating nutrient requirements for faster rates of catch-up growth, as has been done recently for energy and protein [48], in addition to the nutrient requirements formulated for this Consultation for a gain of 5 g/kg/day. Since severely malnourished children pass through a moderately malnourished state on their way to recovery, it is desirable from a practical, logistical standpoint to have the same dietary recommendations for moderate wasting as for rapid weight gain in severe wasting. To achieve rapid rates of weight gain with family foods, micronutrient supplements, including zinc, are likely to be needed. Multivitamins are usually available, and dispersible zinc tablets are becoming more accessible. Thus, to achieve rapid rates of weight gain (e.g., 10 g/kg/day) for wasted children, an immediate practical step could be to recommend family foods plus a dispersible zinc tablet daily for 14 days (as for diarrhea) and a multivitamin syrup (**fig. 1**).

Vitamin E emerged as a problem nutrient when the proposed requirement of 11.5 mg/1,000 kcal was used [5]. This value is based on the Institute of Medicine (IOM) figure, but if the FAO figure or the age-specific IOM requirement is used instead, then vitamin E does not emerge as a problem nutrient. Zinc emerged as a problem nutrient when a tissue deficit was assumed, but a tissue deficit would be unlikely in nonwasted children. Zinc requirements depend on bioavailability, which in turn depends on the phytate:zinc molar ratio. This ratio was consistent with moderate bioavailability in all the patterns except pattern 5, which was borderline. In the proposed nutrient requirements for moderate malnutrition [5], dietary iron is assumed to

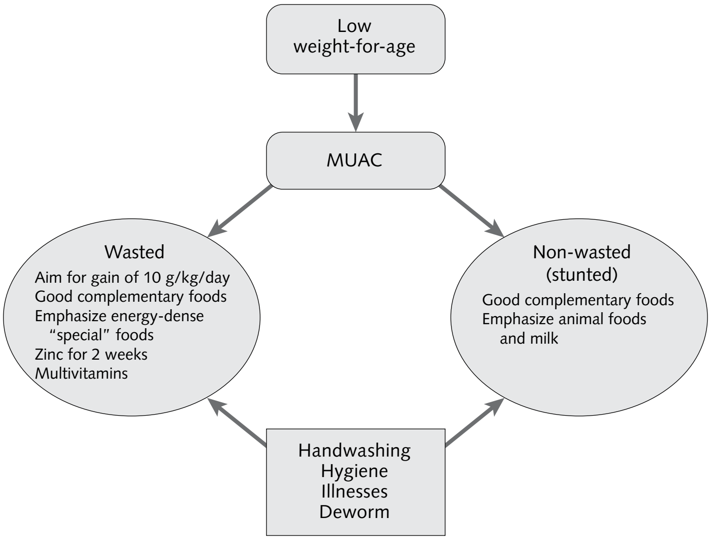

FIG. 1. Diagram showing differential dietary management of malnutrition in moderately wasted and nonwasted, moderately stunted children. MUAC, mid-upper arm circumference

have moderate bioavailability (10% absorption). The bioavailability of food iron is difficult to estimate but may be higher when breastmilk is consumed [49], and it is possible that dietary iron adequacy has been underestimated in pattern 1. Patterns 4, 5, and 6 lacked heme iron, and the only enhancer of nonheme iron absorption present was vitamin C. Whether this iron is of moderate bioavailability will depend on whether the vitamin C–rich foods are eaten contemporaneously with the main dietary sources of iron and whether the enhancing effect of vitamin C is sufficient to offset the inhibiting factors in egg and spinach. If iron had a bioavailability of only 5% in patterns 4, 5, and 6, it would be a problem nutrient, with an intake less than 50% of that required.

In summary:

- Dietary counseling should be an integral part of treating malnutrition.
- Little emphasis is currently given to utilizing family foods for the rehabilitation of malnourished children, whether moderate or severe.
- Current dietary recommendations made to mothers of moderately wasted or moderately stunted children are essentially the same as those given to mothers of well-nourished children.
- Generic dietary recommendations for well-nourished children (as developed by WHO and FAO) may meet the proposed requirements for moderate malnutrition if the recommendations are made slightly more prescriptive.
- Dietary counseling for moderately malnourished children should specifically reinforce the quantities of nutrient- and energy-dense foods that are needed for recovery.
- Successful rehabilitation of moderate malnutrition through dietary counseling demonstrates the value of local foods and could complement efforts to improve infant and young child feeding.
- Using data from Bangladesh and Ghana, linear programming identified vitamin E and zinc as possible problem nutrients in nonbreastfed children, but the vitamin E requirement may be unduly high. Zinc was not a problem for children with no deficit in tissue zinc. Iron was identified as a possible problem nutrient in diets that had no meat.
- Calcium was identified as a possible additional problem nutrient in breastfed children.
- In Bangladesh, rapid rates of weight gain, averaging 10 g/kg/day, have been achieved with family foods and a zinc/iron/multivitamin supplement.
- Counseling about family foods should be considered for the management of moderate malnutrition in food-secure populations.
- Consideration should be given to formulating dietary guidelines that harmonize the dietary management of severe and moderate malnutrition.

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ANNEX 1. Working example: Using WHO job aid–recommended foods appropriate for Bangladesh (115 kcal/kg/day, protein energy percent 12%, energy density 1.1 kcal/g)

Food	g	kcal	Protein (g)	Phytic acid (mg)	Vita-min A (µg RE)	Vita-min E (mg)	Vita-min C (mg)	Thia-mine (mg)	Ribo-flavin (mg)	Niacin (mg)	Vita-min B6 (mg)	Folate (µg)	Vita-min B12 (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)
Morning meal																
Rice	58	75	1.4	35	—	—	—	0.01	0.01	0.5	0.05	1.2	—	1.7	0.12	0.23
Milk	50	33	1.6	—	27	0.05	—	0.02	0.08	0.4	0.05	3	0.2	57	0.05	0.2
Sugar	7	28	—	—	—	—	—									
Snack																
Chapatti	50	60	1.7	47	—	0.25	—	0.01	0.05	2.5	0.08	8.4	—	7.7	1.1	0.78
Egg	50	77	6.3	—	95	1.0	—	0.04	0.25	1.3	0.05	22.0	0.55	25	0.6	0.55
Midday khichuri																
Total weight	158															
Rice	80	104	1.9	48	—	0.01	—	0.02	0.02	0.7	0.08	1.6	—	1.7	0.16	0.32
Lentils	30	35	2.7	107	—	0.33	—	0.06	0.03	0.7	0.06	60	—	5.4	0.99	0.39
Leaves	20	5	0.6	—	82	0.2	2	0.02	0.05	0.24	0.04	29	—	27	0.72	0.2
Pumpkin	23	5	0.1	—	46	0.23	1	0.01	—	0.1	—	3	—	1.6	0.05	0.05
Oil	5	44	—	—	—	0.4	—	—	—	—	—	—	—	—	—	—
Snack																
Pawpaw	155	60	0.9	—	209	1.55	96	0.05	0.05	0.06	—	59	—	36	0.15	0.15
Evening meal																
Total weight	182															
Rice	80	104	1.9	48	—	0.01	—	0.02	0.02	0.7	0.08	1.6	—	1.7	0.16	0.32
Dhal	30	35	2.7	107	—	0.33	—	0.06	0.03	0.7	0.06	60	—	5.4	0.99	0.39
Potato	20	19	0.4	16	—	0.01	3	0.05	—	0.38	0.06	2	—	1	0.08	0.06
Leaves	20	5	0.6	—	82	0.2	2	0.02	0.05	0.24	0.04	29	—	27	0.72	0.2
Oil	7	62	—	—	—	0.6	—	—	—	—	—	—	—		—	—
Guava	25	13	0.2	—	10	0.25	46	0.01	0.02	0.4	0.02	3.5	—	5	0.08	0.05
TOTAL	695	764	23.0	408	551	5.4	150	0.40	0.66	8.9	0.7	283	0.7	204	6.0	4.1
Required [5]		770	18.4		739	8.8	57	0.46	0.61	6.5	0.6	169	0.7	462	6.9	10
% required (problem nutrients)					75%	61%		87%						44%	87%	41%

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Current and potential role of specially formulated foods and food supplements for preventing malnutrition among 6- to 23-month-old children and for treating moderate malnutrition among 6- to 59-month-old children

Saskia de Pee and Martin W. Bloem

Abstract

Reducing child malnutrition requires nutritious food, breastfeeding, improved hygiene, health services, and (prenatal) care. Poverty and food insecurity seriously constrain the accessibility of nutritious diets that have high protein quality, adequate micronutrient content and bioavailability, macrominerals and essential fatty acids, low antinutrient content, and high nutrient density. Diets based largely on plant sources with few animal-source and fortified foods do not meet these requirements and need to be improved by processing (dehulling, germinating, fermenting), fortification, and adding animal-source foods, e.g., milk, or other specific nutrients. Options include using specially formulated foods (fortified blended foods, commercial infant cereals, or ready-to-use foods [RUFs; pastes, compressed bars, or biscuits]) or complementary food supplements (micronutrient powders or powdered complementary food supplements containing micronutrients, protein, amino acids, and/or enzymes or lipid-based nutrient supplements (120 to 250 kcal/day), typically containing milk powder, high-quality vegetable oil, peanut paste, sugar, and micronutrients. Most supplementary feeding programs for moderately malnourished children supply fortified blended foods, such as corn–soy blend, with oil and sugar, which have shortcomings, including too many antinutrients, no milk (important for growth), suboptimal micronutrient content, high bulk, and high viscosity. Thus, for feeding young or malnourished children, fortified blended foods need to be improved or replaced. Based on success with ready-to-use therapeutic foods (RUTFs) for treating severe acute malnutrition, modifying these recipes is also considered. Commodities for reducing child malnutrition should be chosen on the basis of nutritional needs, program circumstances, availability of commodities, and likelihood of impact. Data are urgently required to compare the impact of new or modified commodities with that of current fortified blended foods and of RUTF developed for treating severe acute malnutrition.

Key words: Child malnutrition, complementary food supplements, corn–soy blend, fortified blended foods, micronutrient powder, ready-to-use foods, RUTF, supplementary feeding

Introduction

The treatment of malnutrition, as well as its prevention, among children under 5 years of age requires consumption of nutritious food, including exclusive breastfeeding for the first 6 months of life, followed by breastfeeding in combination with complementary foods thereafter until at least 24 months of age; a hygienic environment (clean drinking water, sanitary facilities); access to preventive (immunization, vitamin A supplementation, etc.) as well as curative health services, and good prenatal care.

In this article, the focus is on possible options for providing a nutritious diet, realizing the constraints faced by many people whose children are at risk for developing or confirmed to be suffering from moderate malnutrition (stunting as well as wasting), such as poverty and food insecurity. Although the nutrient density requirements proposed by Golden [1] are for moderately malnourished children, much of the

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dietary recommendations and complementary food supplements proposed for improving dietary quality are also relevant for young children (6 to 23 months) at risk for developing moderate malnutrition, i.e., among populations with a high prevalence of stunting among children 2 to 5 years of age and wasting among those 6 to 59 months of age. Therefore, much of the discussion in this article is applicable to young (6 to 23 months) and growth-faltering children as well as to moderately malnourished children (wasted children with weight-for-height < −2 and ≥ −3 z-scores or stunted children with height-for-age < −2 z-scores).

We will also cover a range of interventions, from food-assistance programs for people who are wholly dependent on food assistance (refugees, people affected by man-made or disaster-related emergencies) and populations requiring food assistance during lean or bad harvest periods, to populations that are not typically food insecure but consume a relatively monotonous diet with too few good-quality foods to provide vulnerable groups with the required intake of specific essential nutrients (such as micronutrients, macrominerals, essential amino acids, and essential fatty acids).

This article starts with a discussion of options for dietary improvement, modification possibilities for ready-to-use therapeutic foods (RUTFs), improvement of fortified blended foods, and different kinds, roles, limitations, and applications of complementary food supplements. These considerations are then compared with current practices in programs treating moderately wasted children as reported in response to a questionnaire that was sent out by Anne Ashworth and Saskia de Pee between February and August 2008. This assessment of current practices is then followed by programmatic considerations for expansion of the use of new food supplement products for preventing and treating moderate malnutrition among young children.

This article complements the articles in this issue by Golden [1], Michaelsen et al. [2], and Ashworth and Ferguson [3], with Golden having established the nutrient requirements, Michaelsen et al. having reviewed the value and limitations of specific foods and food groups, based on their content of nutrients and antinutrients, and Ashworth and Ferguson having assessed the adequacy of dietary recommendations for moderately malnourished children using locally available foods in relatively food-secure but poor households.

Option 1. Local diet: Required food groups and options for improving nutrient adequacy

Among relatively food-secure populations (i.e., those with adequate energy intake per capita), the primary approach to prevent and treat malnutrition is by providing dietary advice about which foods to consume. Such advice is characterized by emphasis on consumption from all food groups (anywhere between four and eight groups are distinguished), changing the kinds of foods chosen from these food groups (thus, for example, to alternate plant and animal sources of protein), frequent and responsive feeding, and ensuring good energy density [3–5]. The article by Ashworth and Ferguson in this supplement [3] assesses whether and how nutrient requirements proposed for moderately malnourished children can be met by selecting locally available foods and examines the evidence for an impact of diets and programs based on promotion of locally available foods.

Table 1 shows the nutrient groups and active compounds that are essential for good child growth and development together with the main dietary sources of these nutrients and compounds and comments on the consumption of these foods. In summary, a relatively wide variety of foods is required, including breastmilk, staples (for energy and some micronutrients), legumes or lentils (particularly for protein), animal-source foods (good sources of protein, minerals, and some vitamins), vegetables and fruits (for vitamins, minerals, and vitamin C to enhance absorption of nonheme iron), oil (for energy and essential fatty acids), and a source of iodine such as salt (but note that a high sodium intake in moderately malnourished children is not desirable). **Table 2** shows the important characteristics of diets for young malnourished children (adapted from the article by Michaelsen et al. [2]) and considerations with regard to foods required to realize consumption of such diets.

However, as one respondent to the questionnaire on current programs (see below) said:

> …very often the causes of malnutrition are attributable to wide-scale food insecurity.… In such instances, there is simply no choice of food at household level, lack of variety and high market prices create inaccessibility to a diversity of foods, in addition to exhausted household assets with which to purchase or barter and as such, people are often reported to be living off a single staple.… During such times, diet diversity cannot be promoted, so education will focus on the importance of personal hygiene and household sanitation, appropriate breast feeding and timely complementary feeding practices.

Where the diet consists largely of plant foods with very few animal-source foods and fortified foods,* as is the case for many children and their families in developing countries, there are a number of issues to be addressed. As can be concluded from **tables 1** and **2**, plant foods, especially staples (maize, wheat, rice), legumes, lentils, and vegetables, contain considerable

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* Typical fortified foods that tend to be available in developing-country markets are fortified flour, fortified noodles, fortified margarine, fortified milk (powder), and fortified complementary foods.

TABLE 1. Essential nutrients and active compounds and their dietary sources, including recommended home processing where applicable

Nutrients and active compounds of concern	Dietary sources	Comments
Vitamins, plant origin	Vegetables and fruits, grains	Bioavailability (due to antinutrient content of plant foods) as well as absolute quantity of foods to be consumed is of concern
Minerals	Animal-source foods and plant foods	When largely relying on plant foods, intake has to be high (can, for example, be increased by using a dried leaf concentrate), and bioavailability has to be improved, particularly by reducing contents of phytate and polyphenols and/or adding vitamin C. For example, bioavailability of iron is much higher from meat than from vegetables (25% vs. 2%–10%) [6]
Vitamins, animal origin (especially vitamin B_6, vitamin B_{12}, retinol)	Breastmilk, animal milk, organ meat, red meat, poultry, fish, eggs, butter (retinol)	No single animal-source food provides all the MNs that are required from animal-source foods in adequate amounts.[a] Thus, a variety of animal-source foods is required
Iodine	Seafood, including algae, and iodized salt	The use of iodized salt contributes greatly to the prevention of iodine-deficiency disorders (approximately 70% of the world's households are covered)
Proteins, to result in a diet with high PDCAAS score	Soybeans, peanuts, legumes, breastmilk, animal milk, organ meat, red meat, poultry, fish, eggs	Same comment as for vitamins from animal-source foods. A mixture of foods is required to ensure adequate intake of all essential amino acids. Plant sources of protein also have a relatively high content of antinutrients, which affects absorption of minerals
Essential fatty acids, especially those with a favorable n-6:n-3 ratio (~ 6)	Fatty fish or their products, soybean oil, rapeseed oil (also known as canola oil)	Only fatty fish and a few oils have a favorable fatty acid profile, and these are not generally consumed in large amounts in most developing-country diets
Growth factor from milk[b]	Dairy products (breastmilk, animal milk, yogurt, cheese)	Skimmed-milk powder when reconstituted with water is not appropriate for young children because of the lack of fat. Full-cream milk powder is usually skimmed-milk powder to which powdered vegetable fat has been added. When reconstituted with clean, safe water, this is good milk for children. Cheese is not recommended for feeding young malnourished children [2]
Phytase, α-amylase	Present in grains themselves, released when germinating (requires soaking for 24 h), malting (i.e., when germinating or adding malt), or fermenting	These processes require modification of food processing as well as use of whole grains rather than purchased flour. Also, the impact of these food-processing technologies on improving mineral bioavailability and MN status has not been shown to be substantial enough to markedly reduce MN deficiencies

MN, micronutrient; PDCAAS, protein digestibility-corrected amino acid score

a. Even breastmilk is a poor source of certain micronutrients. When a child is born with adequate stores, these stores, in combination with exclusive breastmilk consumption for the first 6 months of life from an adequately nourished mother, will ensure that all needs are met. Introducing complementary foods early reduces the bioavailability of some micronutrients, particularly minerals, from breastmilk and could thus increase the risk of deficiencies when the complementary foods are not of appropriate composition. Children born prematurely or with low birthweight need micronutrient supplements, in addition to exclusive breastmilk consumption, from approximately 2 months of age.

b. The presence of factors in milk (peptides or non-phytate-bound phosphorus that promote growth is very likely but not fully proven as yet) [7, 8].

amounts of antinutrients (such as phytate, polyphenols, lectins, and inhibitors of protease and α-amylase), which reduce mineral bioavailability and interfere with digestion of specific compounds. Therefore, special processing to reduce the content of antinutrients should be used, the content of vitamins and minerals should be increased in order to compensate for the lower bioavailability, or both. Furthermore, oil or sugar should be added to increase energy density.

Figure 1 summarizes options for improving nutritional quality of a largely plant-source based diet when adding animal source foods and fortified foods

TABLE 2. Important characteristics of diets appropriate for young children to prevent and treat moderate malnutrition and considerations

Important characteristics[a]	Considerations
High content of MNs, especially type II nutrients	Calcium, phosphorus, magnesium, and potassium are nutrients that are not contained in most MN formulations such as MN powders and are required in larger amounts (hundreds of milligrams instead of < 10 mg)
High energy density	Fat and sugar increase energy content with minimum increase of volume, but adequate MN content/1,000 kcal of diet or meal needs to be ensured
Adequate protein content High protein quality and availability	Requires mixture of legumes, lentils, and animal-source foods
Low content of antinutrients	Requires processing of staples, legumes, and lentils, industrially or at household level
Adequate fat content Appropriate fat quality, especially n-3/n-6 PUFA content	Requires consumption of 30–40 energy % from fat contributed by foods that have the right fatty acid composition — i.e., fatty fish or its products (fish oil), or soybean, rapeseed, or canola oil
Acceptability: taste, texture, and cultural acceptability	As much as possible, use locally available foods
Easy to prepare	The processing of plant foods to reduce antinutrient content should be done industrially, where (especially urban) populations have good access to such foods, because these are time-consuming and more and more people are switching to use of convenient-to-prepare foods
Affordable	Poverty is the main reason why many children lack an adequate amount of animal-source and fortified foods in their diet Affordable, fortified, processed foods as well as subsidized and for-free distribution options need to be developed
Low risk of contamination	Food-production and food-processing standards need to ensure low risks of microbes, toxins, and contaminants

MN, micronutrient; PUFA, polyunsaturated fatty acid

[a] Source: adapted from Michaelsen et al. [2].

in adequate amounts is not feasible, due to cost or availability issues. The options are divided into procedures that can be performed at home and those that are performed during industrial processing of foods. Home procedures consist of processing and preparation practices using only locally available, unprocessed foods (germination, soaking, or fermenting to reduce antinutrient contents and increase bioavailability, as well as preservation of plant-source foods to increase intake of the micronutrients they can provide) or addition of those nutrients that are lacking through the use of complementary food supplements (i.e., home fortification or point-of-use fortification).

Home-fortification options are discussed in greater detail below (Option 4: Complementary Food Supplements). Very little information is available on the effectiveness of home-processing steps to reduce antinutrient content for increasing mineral bioavailability (which has been the main focus) [2, 9]. For industrial processes, including the use of enzymes, more information is available about their impact [10–12], but none has been implemented at scale for human consumption, for various reasons. However, the recent increase of commitment to reducing child malnutrition and increased understanding of what nutrients and foods are required has also stimulated interest and research and development efforts on the part of food manufacturers to process foods and produce active ingredients for inclusion in special foods or for use in food preparation.

Option 2. Modifying RUTFs for maximizing catch-up growth among moderately malnourished children

We now move from populations with food security but limited access to quality foods to populations facing food insecurity and a high prevalence of child malnutrition, including severe wasting. It is in these populations that RUTFs for treatment of children suffering from severe acute malnutrition used in Community-Based Management of Severe Acute Malnutrition (CMAM) programs are increasingly making a difference to child survival [13–16], and the question has arisen about what foods to provide to moderately malnourished children.

Children suffering from severe acute malnutrition who are being rehabilitated go through a phase of moderate malnutrition before reaching the discharge criteria of having gained adequate weight. Thus, RUTF provides all the nutrients required to promote growth and health among children with severe acute malnutrition and could therefore also, in principle, be considered for treating moderately malnourished children. In fact, its effectiveness for such use has been shown in a study in Malawi [17] as well as in a program in Niger [18].

However, RUTF probably provides nutrients in excess of what moderately malnourished children need, and providing RUTF is not realistic for the vast majority of identified children with moderate malnutrition, due to the limited production capacity of this special product,* ** the cost of the product, and the acceptability of the product where peanuts (an important ingredient) are not commonly consumed. Because of this, efforts are being undertaken to modify the RUTF recipe so that costs are lower and more locally available ingredients are used. **Figure 2** illustrates some of the options that can be considered when trying to modify the RUTF recipe. When just the nutrient content of RUTF is considered, quite a number of options exist for exchange of ingredients. However, when antinutrient content, palatability, processing, storage, and packaging are also considered, the options become more limited.

Four products for moderately malnourished children that are basically modifications of the RUTF recipe have been identified so far, as follows:

» Supplementary Plumpy produced by Nutriset, France. In this product, the skimmed-milk powder of RUTF (Plumpy'Nut) has been replaced with whey and soy protein isolates*** to reduce costs (see **tables 3** and **4**, last categories of products). Otherwise, the ingredients and nutrient contents are the same as those of RUTF. The product is being used in a few programs and in operational studies that assess its impact on linear growth, weight gain, and length of stay in the program among moderately wasted children.

» Project Peanut Butter in Malawi produces a peanut/soybean paste from 25% whole roasted soybean (not dehulled), 20% soybean oil, 26% peanut paste, 27% sugar, and 2% micronutrients (providing 1 RDA per daily dose of 125 g). This product was compared with fortified blended food with additional fish powder, and no difference in linear growth was observed [21]. The absence of milk in the spread and the addition of fish powder to the fortified blended food may explain this absence of difference. Studies are also being done with spreads that include milk powder comparing these spreads with fortified blended food (Likuni Phala). A recent study suggests that such a spread (at 25 or 50 g/day) has a greater impact than fortified blended food on severe stunting but not on weight gain [22]. However, another study that compared milk/peanut spread, soybean/peanut spread, and corn–soy blend found that recovery from moderate wasting was higher in both groups receiving spreads than in the group receiving corn–soy blend (80% vs. 72% recovery) [23].

» Indian RUFC (Ready-to-Use Food for Children) has been developed by WFP India and includes chickpeas, rice flour, a higher amount of oil to replace peanuts, and less skimmed-milk powder to reduce costs. Because chickpeas contain more antinutrients than peanuts and because the milk content has been reduced from 30% in RUTF to 10% in Indian RUFC, the impact on growth and micronutrient status of moderately malnourished children needs to be assessed.

» A baked biscuit has been developed by a consortium of German and Indonesian universities in collaboration with Church World Service that consists of wheat flour, peanut paste, soybeans, oil, sugar, and micronutrient premix and is locally produced in Indonesia. This product also has a higher antinutrient content than RUTF because of the inclusion of wheat flour and soybeans and probably has less impact on linear growth because of the absence of milk.

Although the last three products are likely to be less effective than RUTF, they are presumably better than fortified blended food, the main product that is currently provided to children with moderate acute malnourishment (see sections below on Current Programs for Moderately Malnourished Children and Ready-to-Use Foods vs. To-Be-Prepared Foods: Storage and Preparation).

Option 3. Fortified blended foods: Current composition and improvement options

Fortified blended foods, such as corn–soy blend and

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* The anticipated production capacity of ready-to-use food (RUF) by the Plumpy'field Network of Nutriset, the main producers of RUTF, by the end of 2010 is 63,800 metric tons, [Mamane Zeilani, Scaling up Production of RUF, International Workshop on the Integration of CMAM. FANTA/AED/Washington. 28-30 April 2008, Washington, DC (http://www.fantaproject.org/downloads/pdfs/D3.S8.Zeilani.pdf], which is sufficient to treat 5.3 million of the 19 million children under 5 years of age suffering from severe acute malnutrition worldwide. Of the total anticipated production, 77% will be produced in France and the remaining 23% in 10 countries across Central America, Africa, and the Middle East (300 to 3,000 metric tons/year at each location). The products will include RUTF (Plumpy'Nut) and its related RUF products (Supplementary Plumpy, Plumpy'Doz, and Nutributter). By the end of 2011, production capacity will have reached 100,000 metric tons/year (Mamane Zeilani, personal communication, September 2008).

** At present (December 2008), manufacturers of RUF include Compact, Hilina, Nutriset, Project Peanut Butter, STA, and Valid Nutrition.

*** Earlier versions of Supplementary Plumpy had a somewhat different formulation.

<table>
<tr><th>Local diet: Issues</th><th colspan="2">Modification options</th></tr>
<tr><td rowspan="2">Not enough of
• MNs (cause: low intake of animal-source and fortified foods and low bioavailability)
• n-3 PUFAs
• Essential amino acids</td><td colspan="2">Home fortification to correct too low nutrient intake
• Add MNs (MN powder, lipid-based nutrient supplement, MN-fortified protein powder or dried leaf concentrate [but has limited content of vitamins found in animal-source foods])
• Add n-3 PUFAs (soybean oil [alpha-linolenic acid or ALA], fish oil [docosahexaenoic acid or DHA], separate or added to home fortificant such as lipid-based nutrient supplements)
• Add protein extract or add amino acids, such as lysine, to home fortificant (MN-fortified protein powder or lipid-based nutrient supplement)</td></tr>
<tr><td>Processing of food — at home
• Soaking, germination, malting; requires whole grain (i.e., not applicable to flour) and time
• Fermentation; specific practice for specific foods, not too easy to introduce</td><td rowspan="3">Adding enzymes, when industrially processing food or at home, to reduce phytate content, by
• Soaking fortified blended food ingredients together with phytase, before extrusion cooking and drying; requires equipment (conditioner and dryer)
• Adding phytase to the processed product (note: needs time to act once food has been prepared)
• Adding phytase to prepared product (i.e., home fortification)
Note: Last two options require approval for young human use and a different phytase because of different temperature and pH (see also footnote to fig. 3).
• Using germinated flour for making porridge, as it will then be less thick and have less phytate
• Adding malt to the prepared product (home fortification) to reduce viscosity and phytate content</td></tr>
<tr><td>Too much of
• Phytate (binding minerals, including phosphorus)
• Other antinutrients such as polyphenols, trypsin inhibitors</td><td rowspan="2">Processing of food — industrial
• Roasting, milling, extrusion cooking are normally done but do not have enough impact on phytate content
• Dehulling, degerming; requires specific equipment and results in up to 25%–35% of product being discarded/requiring alternative use (animal feed?) and cost implications
• Malting (as occurs in germination) produces phytase and α-amylase, which reduces phytate content and converts starch into sugars. Using germinated flour for porridge also makes it less thick so that children can consume more
Note: The latter two processes are not normally done</td></tr>
<tr><td rowspan="2">Other issues
• Low energy density in watery porridges
• Bulk and viscosity are limiting intake</td></tr>
<tr><td colspan="2">Increasing energy density
• Adding oil and sugar will increase energy density without increasing volume very much. However, sugar should be added in limited amounts, and adequate micronutrient density (/1,000 kcal) should be ensured</td></tr>
</table>

FIG. 1. Options to modify the currently prevailing local diet, largely consisting of plant foods, to treat moderate malnutrition among children under 5 years of age or prevent it among young children (6–23 mo) where intake of animal-source and fortified foods is limited due to access (affordability and availability) constraints. MN, micronutrient; PUFA, polyunsaturated fatty acid

wheat–soy blend, have been provided as one of the only fortified food-assistance commodities among many different populations, and for a wide range of purposes, for the past 30 years or more. They consist of 20% to 25% soybeans, 75% to 80% corn or wheat, and a micronutrient premix. Because of the protein content and quality (total protein digestibility-corrected amino acid score [PDCAAS] of corn–soy blend: 65%) from the soybeans and the additional micronutrients, fortified blended foods have been regarded as being of reasonably good nutritional value for limited cost and are being produced in more than 20 countries around the globe. Fortified blended foods also became the products of choice from the few nonperishable food items used in food-assistance programs* to be provided to moderately malnourished children as well as other vulnerable groups (pregnant and lactating women and people chronically ill with HIV/AIDS or tuberculosis). In 2007, WFP distributed 242,000 metric tons of fortified blended foods, including 192,000 metric tons of corn–soy blend, to specific groups as well as to general populations because of the micronutrient and protein contents.

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* Items included in the food basket used in food-assistance programs typically include staples (whole grains of rice, wheat, and/or corn, or flour in the case of wheat and corn; flour has a shorter shelf-life than whole grains but can, and should, be fortified), pulses (grams, lentils), cooking oil (fortified with vitamin A), iodized salt, and fortified blended foods (the main source of micronutrients unless fortified flour is part of the food basket).

RUTF		Steps to be explored for reducing costs and increasing local production		
Positive	**Negative**	**Modify from…**	**…to, options**	**Comments/drawbacks**
• Shown to promote growth very well • Can be safely stored and used in communities and households	• Production capacity not enough to also treat moderate acute malnutrition • Costs of ingredients are high, especially milk • Peanut taste is not familiar in certain parts of the world (e.g., South Asia), and in those places peanut availability is also limited	• 30% full-fat milk powder • 25% ground peanuts • 15% soybean or rapeseed/canola oil • 28% sugar (lactoserum, maltodextrin) • 2% vitamins and minerals, including macrominerals (type II nutrients)	• Lower the milk content • Replace milk powder with whey concentrate • Use soy protein isolates (provided that phytate content is lower) • Use other legumes, such as beans, peas, or lentils, instead of peanuts • When replacing peanuts, their oil content needs to be compensated for	• Minimum milk content is unknown • Whey availability is linked to cheese production • If milk contains growth factor, soy protein is disadvantageous • Protein content of lentils and beans is comparable to that of soybeans and peanuts (20–30 g/100 g vs. 35 and 23g/100 g, respectively), but they contain very little fat (< 1 g/100 g vs. 18 and 45 g/100g, respectively) and have relatively high amounts of phytate and other antinutrients. Thus with how to reduce antinutrients, enzymes? • Texture, consistency, and homogeneity to be adapted

FIG. 2. Steps to be explored for the development of an effective ready-to-use supplementary food of lower cost than ready-to-use therapeutic food (RUTF) for moderately malnourished children

However, fortified blended foods are not well adapted to meet the nutritional needs of young or moderately malnourished children, for several reasons [24–27]:

- They do not contain all the required nutrients in adequate amounts;
- They contain a relatively large amount of antinutrients and fibers, especially when prepared from non-dehulled soybeans and nondegermed, nondehulled maize or wheat (see below);
- They do not provide enough energy per serving and are bulky;
- The overall fat content and essential fatty acid levels are low;
- They contain no milk powder, which increasingly appears to be important for linear growth of young malnourished children [7, 8].

The issue of too low energy density has been partly addressed in supplementary feeding programs by providing the corn–soy blend (or wheat–soy blend) together with oil and sugar (commonly reported weight-based ratio, 10:1:1; see program section, **'Current programs for moderately malnourished children',** below for more information on ratios used). Sometimes these ingredients are mixed together in the feeding or health center before distribution; other times they are provided alongside corn–soy blend to be mixed at home. Unfortunately, very little is known about the preparation and consumption of corn–soy blend at home, both by the malnourished child and by his or her family members.

Figure 3 summarizes the advantages and disadvantages of corn–soy blend and other fortified blended foods when provided to young moderately malnourished children, as well as options that are or may be considered for improvement. The options for improving the nutritional quality range from modifications that are relatively easy to implement (changing micronutrient premix, adding milk powder, dehulling soybeans) to those that require substantial adjustments to the production process (degerming maize, adding more oil during production, exploring use of phytase during production).

To limit the costs of improving corn–soy blend, some of the improvements could be applied to fortified blended foods used for young malnourished children but not necessarily to fortified blended foods used for other vulnerable groups (pregnant and lactating women, people suffering from HIV/AIDS or tuberculosis). For practical reasons, however, the number of different varieties of fortified blended food used in an operation should be limited (preferably to not more than two) in order not to confuse program implementers and beneficiaries with different, but very similar, products for different target groups that all have to be distributed and prepared separately.

The three main buyers and distributors of corn–soy blend are the World Food Programme (WFP), UNICEF, and the US Agency for International Development (USAID). The characteristics of the products they purchase are described below.

TABLE 3. Classification of complementary food supplements

Kind of product (examples)	Nutrients and active substances contained	Ingredients used	Impact shown or expected	Most appropriate target groups
MN powders (Sprinkles, MixMe)[a]	MNs (type I and zinc)	MNs and carrier (maltodextrin or rice flour)	Yes, on nutritional anemia Assumed to have impact on other MN deficiencies as well	Those with MN deficiencies; not very effective for promoting linear growth
Powdered complementary food supplements, consisting of protein and/or specific amino acids and MNs (Ying yang Bao, TopNutri)	MNs, some with macrominerals (i.e., type II nutrients), high-quality protein, or limiting amino acids	MNs, soy protein concentrate or processed whole-fat soybean flour (also contains essential fatty acids), additional amino acids (lysine) for some	Formulation using whole-fat soybean flour with 6 mg iron as NaFeEDTA,[b] impact shown on anemia and linear growth Providing several nutrients essential for linear growth Impact depends on bioavailability of vitamins and minerals and should possibly be enhanced with dairy protein and essential fatty acids	Those at risk for faltering linear growth (6–24 mo) Impact on growth remains to be proven
Powdered complementary food supplements, consisting of protein and/or specific amino acids, enzymes, and MNs (MixMe Plus)[c]	MNs, macrominerals for some (i.e., type II nutrients), high-quality protein or limiting amino acids, enzymes for malting or phytate destruction	MNs, macrominerals (calcium, potassium, magnesium?), lysine, malt	Impact not yet shown Fortificants should impact MN deficiencies, type II nutrients, and lysine to impact growth, and reduced viscosity to increase energy intake Note: contains no dairy protein or essential fatty acids	Those at risk for faltering linear growth (6–24 mo) Impact to be confirmed
Lipid-based nutrient supplement ≤ 20 g, ~ 108 kcal (Nutributter)	MNs, macrominerals, dairy protein, essential fatty acids (n-3 PUFAs)	**Nutributter**: Peanut paste, sugar, vegetable fat, skimmed-milk powder, whey powder, MNs, maltodextrin, cocoa, lecithin	Yes, study from Ghana showed impact on MN deficiencies, linear growth, motor development [19, 20]	Those at risk for faltering linear growth (6–24 mo) Appears to be most comprehensive complementary food supplement to make up for gap of essential nutrients in complementary foods, but does not compensate for low energy intake nor counteract impact of antinutrients consumed from other foods.

continued

TABLE 3. Classification of complementary food supplements (*continued*)

Kind of product (examples)	Nutrients and active substances contained	Ingredients used	Impact shown or expected	Most appropriate target groups
Good-quality complementary food to be prepared using boiled water, 30 g powder with < 120 mL water provides ~ 120 kcal	MNs, macrominerals, high-quality protein, carbohydrates, vegetable fat	Typical commercially available porridges, made from skimmed-milk powder or soy protein, vegetable fat, rice/corn/wheat/oats, sugar, MNs	Impact not studied More impact expected on growth as well as MN status from porridges containing milk powder rather than soy protein MN content varies widely	Those at risk for faltering linear growth (6-24 mo) Impact to be confirmed
Lipid-based nutrient supplements ≤ 50 g, i.e., high-quality nutrient and energy supplement, ~ 250 kcal (Plumpy'Doz, Indian RUFC)	MNs, macrominerals, high-quality protein, high-quality oil with good n-6:n-3 fatty acid ratio, energy largely from oil and protein	**Plumpy'Doz:** Peanut paste, vegetable fat, sugar, skimmed-milk powder, whey powder, MNs, maltodextrin **Indian RUFC**: Chickpeas, soybean oil, sugar, rice flour, skimmed-milk powder, MNs, soy lecithin	Impact of **Plumpy'Doz** currently being studied Composition is based on RUTF (Plumpy'Nut), but consumed in small amount added to daily diet Question: Are all nutrient needs met and antinutrient effects of other foods overcome? **Indian RUFC** composition and production processes being finalized, subsequently to be tested	Those at risk for faltering linear growth and morbidity during highly food-insecure periods
Lipid-based nutrient supplements ≤ 100 g, i.e., high-quality nutrient and energy supplement, ~ 500 kcal (Plumpy Nut, Supplementary Plumpy, Indian RUFC[d]) Note: Compressed bars and biscuits (BP100) can also be included in this category	MNs, macrominerals, high-quality protein, high-quality oil with good n-6:n-3 fatty acid ratio, energy largely from oil and protein	**Plumpy'Nut:** Peanut paste, sugar, vegetable fat, skimmed-milk powder, whey powder, maltodextrin, MNs, cocoa, lecithin **Supplementary Plumpy:** Peanut paste, sugar, vegetable fat, whey, soy protein isolates, maltodextrin, cocoa, MNs, lecithin **Indian RUFC**: Chickpeas, soybean oil, sugar, rice flour, skimmed-milk powder, MNs, soy lecithin	Impact of **Plumpy'Nut** (or other RUTFs) on growth and MN status has been shown among children suffering from severe acute malnutrition who progressed through moderate acute malnutrition stage to normalcy Note that these children received no other food than RUTF and breast milk, if applicable, during recovery Impact of **Supplementary Plumpy** currently being studied **Indian RUFC** composition and production processes being finalized, subsequently to be tested	Those suffering from moderate acute malnutrition, i.e., in targeted supplementary feeding programs, or for blanket supplementary feeding of young children in highly food-insecure periods or areas

MN, micronutrient; PUFA, polyunsaturated fatty acid; RUFC, ready-to-use food for children; RUTF, ready-to-use therapeutic food

a. *Moringa oleifera* leaf powder could also be considered a micronutrient supplement, but because its composition, including levels of antinutrients and toxic substances, is not well known, it is not included in this table.

b. Note that the Joint FAO/WHO Expert Committee on Food Additives (JECFA) norms for EDTA intake translate to a maximum of 2.5 mg iron from NaFeEDTA for an 8-kg child.

c. Power Flour consists of barley malt but has not been fortified with micronutrients; therefore it has not been listed here.

d. When Indian RUFC is to provide 500 kcal/day, micronutrient content per 1,000 kcal of product will be lower than when providing 250 kcal/day.

Corn–soy blend from WFP*

WFP is currently revising its specifications for corn–soy blend and other fortified blended foods to arrive at mainly two products,** as follows (for more details, see de Pee et al. [28]):

» *Improved corn–soy blend* for general use, including for pregnant and lactating women and people suffering from HIV/AIDS or tuberculosis, which will:
  - Have improved micronutrient content (more kinds, increased amounts, better bioavailability);
  - Use dehulled soybeans in order to make a start with reducing fiber and phytate content and to reduce the content of toxins and contaminants;
  - Have a lower maximum for aflatoxins (5 instead of 20 ppb) and tighter specifications for microbiological content;
  - Include specifications for maximum content of heavy metals;

» *Improved corn–soy blend plus milk* for young (6 to 23 months) and moderately malnourished children, which will have the same specifications as improved corn–soy blend (see above) and in addition contain:
  - Skimmed-milk powder at 8%;
  - Sugar: up to 10% of energy;
  - Oil (soybean): approximately 3% added before extrusion and up to 7% added after extrusion (exact amount to be determined based on product rancidity and shelf-life tests).

The specifications for improved corn–soy blend have been finalized and will be gradually implemented in consultation with producers. For corn–soy blend plus milk, production trials are ongoing to determine the optimal specifications from a technological and shelf-life point of view. Once finalized, this product should be studied in comparison with other products (RUTF, improved corn–soy blend) for its impact on growth (linear growth as well as weight), micronutrient status, functional outcomes, acceptance, and length of stay in blanket or targeted supplementary feeding programs among young (6 to 23 months) as well as moderately malnourished children.

Corn–soy blend from UNICEF (UNIMIX)

UNIMIX, the corn–soy blend procured and distributed by UNICEF, has virtually the same composition as (not yet improved) corn–soy blend procured by WFP, except that it also includes 5% to 10% sugar in exchange for corn. WFP and UNICEF are discussing the improvements that will be made to corn–soy blend and also to UNIMIX.

Corn–soy blend from USAID

The corn–soy blend procured and distributed by USAID complies with the USDA (US Department of Agriculture) Commodity Requirement CSB13 [29] and contains 69.5% cornmeal (“processed, gelatinized”), 21.8% soybean flour (“defatted, toasted”), 5.5% soybean oil (“refined, deodorized, stabilized”), 3% micronutrients, and antioxidant premix. The declared micronutrient content of corn–soy blend from USAID*** is based on the micronutrient content of the raw materials and the micronutrient premix, not on analysis. And, as with the corn–soy blend purchased by WFP, the micronutrient specifications for the premix are currently under review as well (Liz Turner, SUSTAIN, personal communication).

According to the CSB13 requirements, corn shall be dehulled and degermed and corn germ may be added back to the product (maximum 10%) to replace vegetable oil. Soybeans can be added as defatted or full-fat soybean flour. Defatted soybean flour shall be prepared from dehulled soybeans, whereas dehulling is optional for full-fat soybean flour. When full-fat soybean flour is used, it should be added in an amount that ensures that protein content is equivalent to use of 21.8% defatted soybean flour. Vegetable oil may be added to the final product to ensure adequate fat content.

Thus, the corn–soy blend donated by USAID contains less crude fiber, which is also in accordance with the specifications (2% dry matter for USDA specifications and 5%, to be changed to 3%, for WFP), because it uses dehulled (and possibly degermed) corn, and possibly dehulled soybeans (depending on whether defatted or full-fat soybeans are used). For this product, some processing steps identified in **figure 3** are thus being taken already.

A comprehensive overview of the history of US Government Food Aid Programs has been written by Marchione [30]. It is noteworthy that between the mid-1960s and the late 1980s, blended foods contained nonfat dry milk (corn–soy milk and wheat–soy milk) but that milk was dropped from the blends when milk surpluses became exhausted. In 2001, nonfat dry milk was reintroduced in a number of commodities. Requirements for adherence to manufacturing standards, including micronutrient specifications, for US commercial food suppliers to the food aid programs, and their enforcement, were introduced in 1999 and

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* WFP also distributes corn–soy blend donated by USAID and formulated according to USDA specifications, see section below, **‘Corn-soy blend from USAID’.** Here, we describe the specifications of corn–soy blend as purchased by WFP, to a large extent from producers in developing countries.

** In North Korea, WFP purchases blended foods that also include milk powder (milk powder, corn, and soy; milk powder and rice; milk powder and wheat). However, no conclusive evaluation of impact is available on these operations.

*** Available at: http://www.usaid.gov/our_work/humanitarian_assistance/ffp/cr g/downloads/fscornsoyblend.pdf.

TABLE 4. Composition and price, per daily recommended dose, of various complementary food supplements that are already being used or are in final stage of development (see **table 3** for classification and ingredients)

Ingredient	MN powders, nutritional anemia (1 g)	MN powders, 15 vitamins and minerals (1 g)	Soy Sprinkles (10 g)	MixMe Plus (5 g)	TopNutri (7.5 g)	Nutributter (20 g)	Plumpy' Doz, (46 g)	RUFC India[a] (50 g)	Supplemen-tary Plumpy (92 g)	Plumpy' Nut (92 g)
Energy (kcal)			44		20	108	247	260	500	500
Protein (g)			3.8		3.8	2.56	5.9	5	12.5	12.5
Fat (g)			3		< 0.1	7.08	16	15.5	32.9	32.9
Lysine (mg)				400	36% excess					
Malt flour (mg)				1,000						
PDCAAS (%)					100					
Vitamin A (µg)	300	400		400	340	400	400	100	840	840
β-Carotene (µg)								400		
Vitamin E (mg)		5		5	5.6	—	6	3	18.4	18.4
Vitamin B_1 (mg)		0.5		0.5	0.5	0.3	0.5	0.25	0.55	0.55
Vitamin B_2 (mg)		0.5	0.2	0.5	0.7	0.4	0.5	0.25	1.66	1.66
Niacin (mg)		6		6	6.8	4	6	3.7	4.88	4.88
Pantothenic acid (mg)				2	3	1.8	2	0.5	2.85	2.85
Folic acid (µg)	160	150		90	90	80	160	75	193	193
Vitamin C (mg)	30	30		60	45	30	30	30	49	49
Vitamin B_6 (mg)		0.5		0.5	0.6	0.3	0.5	0.25	0.55	0.55
Vitamin B_{12} (µg)		0.9		0.9	0.9	0.5	0.9	1	1.7	1.7
Calcium (mg)			385	400	320	100	387	200	276	276
Magnesium (mg)					90	16	60	40	84.6	84.6
Selenium (µg)		17		17	20	10	17	10	27.6	27.6
Zinc (mg)	5	4.1	4.1	2.5	3.8	4	9	4.1	12.9	12.9
Iron (mg)	12.5	10	6	2.5	7.7	9	9	10	10.6	10.6
Iodine (µg)		90		30	86	90	90	—	92	92
Copper (mg)		0.56		0.34	0.34	0.2	0.3	0.3	1.6	1.6
Phosphorus (mg)					230	82.13	275	75	276	276
Potassium (mg)				400	280	152	310	305	511	1022
Manganese (mg)					0.9	0.08	0.17	0.8	—	—
Vitamin D (µg)		5	280 IU	5	4.9	—		2.5	15	15
Vitamin K (µg)					37.5	—		15	19.3	19.3
Biotin (µg)					18.8	—			60	60

Sodium (mg)					70					
Molybdenum (μg)					7.5					
Chromium (μg)					7.5					
Phytomenadion (μg)				30						
Product cost per dose (US$)	0.02	0.027[b]	?	0.04?	?	0.11	0.2	0.13 (0.26 for 100 g)	0.33	0.41
Minimum no. of doses for 6- to 23-mo-old	225 (150/yr)	225 (150/yr)		225 (150/yr)	225 (150/yr)	180 (daily 6–12 mo)	120?	120?	120?	120?
Total product cost (US$) for required no. of doses	4.5	6.1		9		19.8	24	15.6	39.6	49.2
Supplement to or replacement of normal diet	Supplement	Supplement	Supplement	Supplement	Supplement	Supplement	Supplement or replacement	Supplement or replacement	Replacement	Replacement

MN, micronutrient; PDCAAS, protein digestibility-corrected amino acid score

a. The micronutrient premix that is added to Indian ready-to-use food for children (RUFC) is being modified. The composition shown here was the initial composition and has been used for the calculations in **table 5D–F** and **table 6**.

b. Cost for single-dose packaging. For multidose packaging, cost could go down to US$0.008/dose.

2000. With a total US donation in 2007 of 114,000 metric tons of corn–soy blend, 61,000 metric tons of which was donated through WFP,* good quality control is very important.

Need and feasibility of further adjustments to fortified blended food

As mentioned above, one of the main issues with corn–soy blend that make it less suitable for young malnourished children is the high content of antinutrients, particularly phytate, and its fiber content. A study from 1979 documented that nitrogen absorption and retention (indicating protein uptake) were better from corn–soy blend made from degermed corn and dehulled soybeans than they were from corn–soy blend made from whole cornmeal and dehulled soybean flour or from whole cornmeal and whole soybean flour [23]. These effects were ascribed to the higher fiber content. High fiber content may also reduce energy intake through an effect on appetite, increased fecal losses of energy due to reduced absorption of fat and carbohydrate, and increased flatulence, which can have a further negative effect on energy intake [2] and can also lead to nonacceptance of the product. Although reduced energy uptake could be compensated for by adding oil or sugar to the product, it does not improve mineral bioavailability and also reduces micronutrient density unless fortification levels are increased.

An article by Jansen published in 1980 that reviewed more results, however, concluded that degerming corn also results in loss of protein and oil from the germ and that the higher protein content of whole corn compensates for the slightly lower protein absorption related to its higher fiber content [25]. With regard to the likely lower bioavailability of minerals, Jansen said that this should be compensated by fortification. Given the considerable losses when degermed corn meal is used (extraction rate of 65% to 75%, and thus a loss of 25% to 35%), the desire to produce the product locally, and the possibility to at least dehull the soybeans, Jansen recommended in 1980 that corn–soy blend be composed of dehulled soybeans and whole maize meal, resulting in a crude fiber content of less than 2%, and be mixed with an adequate micronutrient premix.

The USDA specifications include the use of dehulled and degermed corn and dehulled defatted soybeans or optionally dehulled full-fat soybean flour, and up to 10% of corn germ may be added back to the product. Corn–soy blend purchased locally in developing countries by both WFP and UNICEF, however, is made from

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* Details about USDA Food Aid can be retrieved from Programs and Opportunities — Food Aid — Food Aid Reports (available at: http://www.fas.usda.gov/excredits/FoodAid/Reports/reports.html).

Fortified blended foods		Options for improving nutritional quality		
Positive • Can be produced almost anywhere • Soybeans: good protein profile • Fortified with micronutrients	**Negative** • Limited impact on growth and MN status • Fiber in nondehulled maize, wheat, and soybeans • Antinutrients in nondegermed maize as well as in wheat and soybeans • Fortified with too few MNs and limited bioavailability • Energy density too low and viscosity too high for young malnourished children	**Limited complexity** • Add dried skimmed milk to promote growth (10%?) • Soybeans: dehulling • Improve MN profile (more MNs and higher amount)	**More complex and costly** • Use soy protein isolates with low phytate content instead of dehulled soybeans • Use degermed and dehulled maize flour (means discarding 25% of maize and altering production steps) • Add sugar (already done for UNIMIX) and oil (soybean, rapeseed/canola) during processing to increase energy density and essential fatty acid content and compensate for oil lost when soy protein isolates rather than soybeans are used	**Worth exploring — phytase[a]** • Reduce phytate by soaking fortified blended food ingredients together with phytase before extrusion cooking and drying (requires equipment: conditioner and dryer) • Reduce phytate by adding phytase to the processed dry product • Reduce phytate by adding phytase to prepared product (i.e., home fortification)

FIG. 3. Steps to be considered for upgrading fortified blended foods to supplementary foods of better nutritional quality for moderately malnourished children. MN, micronutrient

whole maize as well as whole soybeans.*

A study using wheat–soy blend provided by World Vision in Haiti found a poor impact on anemia levels [31]. If the wheat–soy blend was provided under the Title II programs and complied with USDA specifications, the crude fiber content was 2.5% of dry matter, as it contained partially debranned wheat [32]. This means that also for corn–soy blend that complies with USDA specifications it is not known whether the phytate content is low enough to provide for adequate mineral absorption. For young children, a maximum intake of total dietary fiber of 0.5 g/kg body weight has been recommended by the American Academy of Pediatrics. For a 6-kg child, this would translate into 3 g/day. When this child consumes some vegetables and wheat or corn in addition to one or two cups of corn–soy blend, especially when the blend is made from whole maize and whole soybeans, the intake is very likely higher than that.

Therefore, options to reduce fiber and phytate content need to be further explored for the product purchased by WFP and UNICEF. The costs of degerming corn, due to the need for specific equipment, the loss of 25% to 35% of the corn, and the need to compensate for the loss of some protein and oil, are high. This means that if degerming corn were to be done for the products purchased by WFP and UNICEF, it should probably only be done for corn–soy blend that is used for young (6 to 23 months) and for moderately malnourished children.

Option 4. Complementary food supplements: Compensating for shortage of specific nutrients

Complementary food supplements can be defined as food-based complements to the diet that can be mixed with or consumed in addition to the diet and the purpose of which is to add nutritional value [33]. Complementary food supplements are comparable to food fortification in the sense that they increase the intake of essential nutrients from food. However, the important differences are that complementary food supplements can be targeted to specific vulnerable groups, as they are added to foods just before consumption (home or point-of-use fortification), and that the dosage is not dependent on the amount of energy consumed in a day, i.e., one dose is added to one meal irrespective of meal size.

Complementary food supplements can be divided into different categories, as shown in **table 3**. The first four categories (micronutrient powders, powdered complementary food supplements [protein, amino acids, micronutrients], complementary food supplements that also have active substances (enzymes), and lipid-based nutrient supplements of 10-20 g) are complementary food supplements that provide essential micronutrients, amino acids, fatty acids, and/or active compounds (enzymes) but contain little additional energy. The next three categories (industrially produced complementary foods, 45 g lipid-based nutrient supplements [250 kcal], and 90 g lipid-based nutrient supplements [500 kcal]) are foods of high nutritional

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* Note that the new specifications of WFP that will soon be rolled out require dehulling of soy (see above), and maximum crude fiber will be reduced from 5% to 3%.

value* that also provide a substantial amount of energy. Because they are meant to be consumed in addition to a daily diet, even when partly replacing it, and are composed in such a way that they are the main source of essential nutrients (i.e., they can be combined with a largely staple based diet little more than just carbohydrate sources), they are included in this table on complementary food supplements.

Because complementary food supplements are added to an existing diet, the added value of a particular complementary food supplement depends on the composition of the diet to which it is added and the needs of the target group or individual consuming it. For example, micronutrient powders were originally developed to address nutritional anemia [34] and were then expanded to include a wider spectrum of micronutrients [35]. However, when choosing (or developing) a complementary food supplement to enrich the diet of young (6 to 23 months) or moderately malnourished children, a commodity with additional nutrients, such as essential amino acids and essential fatty acids and a dairy component, may be more appropriate, assuming that local foods do not provide these in sufficient amounts.

Because the concept of complementary food supplements is relatively new, with micronutrient powders developed in the late 1990s being the first, they differ with regard to important ingredients, relatively few data exist on their impact, and depending on their purpose, only certain outcomes have yet been tested [19–22, 34, 36]. However, the concept is promising, because only the additionally required nutrients are added to an otherwise local diet or basic food ration. This limits costs as well as interference with prevailing dietary habits and sourcing of food-assistance commodities. Programmatic experience is required to evaluate the feasibility of their use, including prevention of sharing, required social marketing messages, package design and consumer information, training needs, etc., because the concept of a small food supplement to be consumed exclusively by a specific age group of young children [35].

Table 4 shows the nutrient content, sample price per daily dose as in early 2009, estimate of the number of doses required between 6 and 23 months of age or to treat moderate malnutrition, and price of this number of doses (for further information on fortified complementary foods and supplements see the article by the Infant and Young Child Nutrition Working Group [37]). Clearly, the more nutrients and the more energy the complementary food supplement contains, the more expensive it becomes. However, it is important to realize that the complementary food supplement provides nutrients that would otherwise have to be supplied by a much more diverse diet.

Some adequacy calculations

In order to determine which kinds of complementary food supplements are most suitable to improve a typical complementary feeding diet so that it is likely to meet the nutrient intakes recommended by Golden [1] for moderately malnourished children, **table 5** was prepared using linear programming [38, 39]. It shows the typical nutrient intake of a 12- to 15-month-old, moderately underweight (7.4 kg) Bangladeshi child who is breastfed and receives three servings of locally prepared complementary food per day, consisting of rice, dhal with potatoes, oil, sugar, and dark-green leafy vegetables (a maximum of three portions per day of each) and with or without fish (a maximum of two portions per day) when receiving various types of complementary food supplements. The portion sizes assumed for the local foods are average sizes, and they have been modeled to provide the energy requirement not yet fulfilled by complementary food supplements, breastmilk (40% of total energy intake), and a standardized portion size of rice of 150 g/day (i.e., 23% of total energy intake). The linear programming goal was to achieve the nutrient intakes proposed by Golden [1] and the same as those used in the article by Ashworth and Ferguson [3]. However, it should be noted that the selection of foods for the analyses done in this article was more restricted than in Ashworth and Ferguson's article (up to 9 vs. 24 local foods). In particular, fruits, milk, chapatti, bread, semolina, pumpkin, chicken, and chicken liver were not included here, as it was assumed they may not be available in the poorest households. This makes this analysis very different from the one presented by Ashworth and Ferguson, where a greater selection of foods and somewhat different portion sizes were used.

From **table 5A** to **5B** (kinds of micronutrient powders and powdered complementary food supplements) and from **table 5C** to **5D** (kinds of lipid-based nutrient supplements), the dietary diversity is reduced by excluding fish. Diets that included lipid-based nutrient supplements had a lower dietary diversity in the best-fit model than diets with micronutrient powders or powdered complementary food supplements (**table 5A** to **5D**). The lower dietary diversity is because the energy contribution from lipid-based nutrient supplements (i.e., 12.7% to 57.5% of total energy intake) partly replaced that of local foods.

For the unsupplemented restricted diet, which includes spinach, dhal, potatoes, fish (two kinds), oil, sugar, rice, and breastmilk, without a complementary food supplement, nutrient content is inadequate for 10 micronutrients. With a micronutrient powder with

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* It should be noted though that the nutritional value of commercially available complementary foods is very variable. They have been listed here, because some are of high value, such as the products developed by Groupe de Recherche et d'exchange Technologiques (GRET) (see **table 8**).

5 micronutrients, content is inadequate for 7 micronutrients, and with 16 micronutrients it is inadequate for 3, which are type II nutrients. Of all the different kinds of micronutrient powders and powdered complementary food supplements, TopNutri provides the most complete mix of micronutrients. With decreasing dietary diversity, the gap of micronutrients increases. When lipid-based nutrient supplements are added, nutrient intake becomes more complete as compared with when micronutrient powders are added. However, they are still short in a number of nutrients, especially vitamins E and C, potassium, magnesium, and zinc. This may be due to the fact that some lipid-based nutrient supplements are designed for prevention rather than for treating moderate malnutrition (i.e., recommended intakes are different), and other lipid-based nutrient supplements are designed to completely meet the required nutrient intake (with exact intake to be varied according to energy need) rather than to be consumed in addition to a local diet and breastmilk. For the Indian RUFC, the micronutrient content will be adjusted to be comparable to that of Plumpy'Doz when providing 50 g/day and to Supplementary Plumpy when providing 100 g/day.

The same analysis has also been done for the addition of complementary food supplements to corn–soy blend, of which the energy density was increased by the addition of oil and sugar (**table 6**). For corn–soy blend, the composition as published by USDA was used, which is based on the micronutrient content of the raw ingredients and the micronutrient premix and is a relatively complete kind of corn–soy blend. As the table shows, because complementary food supplements are not designed to be added to corn–soy blend, which is already fortified, the intake of several micronutrients would become rather high. However for some, particularly the type II nutrients, intake would still be too low, for similar reasons as mentioned above for the combination of lipid-based nutrient supplements with the local diet. It will be best either to adapt the mew micronutrient premix formulation of corn–soy blend (as will soon be implemented by WFP) or to add an appropriate complementary food supplement to a largely plant-source-based unfortified diet. When adapting corn–soy blend, considerations discussed above should also be taken into account, i.e., ingredients and processing used, in addition to reaching adequate nutrient content.

The results shown should, however, be interpreted with caution, because they are calculated for a hypothetical child aged 1 year, weighing 7.4 kg, who is breastfed, probably by a mother with suboptimal nutritional status herself, and lives in a food-insecure household in Bangladesh. For many children, the situation will be different because they are of a different age, may or may not be breastfed, may have access to a greater variety of foods, etc. The complementary food supplements are of the same size and composition irrespective of the specific age of the under-five child, whether he or she is breastfed, and what the nutritional status is. Thus, adequacy of diet in combination with complementary food supplements will vary among as well as within populations.

Linear programming calculates possible solutions to reach certain goals, such as, in this case, intake of energy, macronutrients, and micronutrients from a specific set of foods that can be consumed at certain minimum and maximum amounts. However, some important aspects of foods for young or moderately malnourished children discussed in this article cannot yet be included in linear programming because of a lack of adequate data or because exact requirements have not yet been established. These include selenium, iodine, biotin, and vitamins K and D (too variable or unknown content); essential fatty acids; PDCAAS, i.e., protein quality; minimum requirement for animal-source food or milk; antinutrients (content in individual foods not well known and maximum intake not established); and micronutrient bioavailability (depends on factors in a meal, not a daily diet, and is very complex).

Further, the linear programming results are very dependent on the model parameters, which for this particular analysis include the list of foods, their portion sizes, and the desired nutrient intake levels. Thus, for households with access to a greater variety of foods or with different food portion size restrictions, the results would differ, as was shown when results from these analyses are compared with those for a breastfed child in Ashworth and Ferguson [3]. Likewise, these results depend on the validity of the nutrient goals modeled. In particular, estimating iron adequacy is complex because it depends on bioavailability, which needs to be judged separately. An additional judgment is also required with regard to protein and fat quality and inclusion of milk powder or another animal-source food (in addition to breastmilk).

Future option: Use of phytase

Another possible option to increase mineral bioavailability is the use of phytase to reduce phytate content, by adding it during production, adding it to an end product as the last production step, or using it as a home fortificant (**fig. 3**). The latter two options, however, cannot yet be used at large scale because phytase is not yet widely approved for human consumption. It has GRAS (Generally Regarded As Safe) status for persons aged 3 years and older, but not yet for younger persons, and in some countries it is not permitted at all. When phytase is used during industrial processing and destroyed by a subsequent heating step, there is no problem because the product that reaches the consumer will not contain phytase.

A range of phytases is available with different pH and temperature optimums; thus different phytases can be used for phytate degradation in different wet foods or in the low-pH environment of the stomach [40]. To what extent phytase reduces phytate, whether used during food production, in prepared, wet, food that is left to stand for a while, or in the stomach, needs to be determined, as should the impact on mineral absorption. Promising results have been obtained from a very recent stable-isotope trial among Swiss women that assessed iron absorption from a maize porridge with high phytate content to which a micronutrient powder with low iron content of high bioavailability and a phytase that degrades phytate both on the plate and in the stomach had been added [41].

Thus, it is of urgent importance to obtain GRAS status for the use of phytase in foods consumed by

TABLE 5A. Comparing nutrient intake requirements as proposed by Golden [1] with the nutrient contents of a daily diet of a 13- to 15-month-old, breastfed, moderately malnourished Bangladeshi child (7.4 kg, 851 kcal/day) to which fixed amounts of different complementary food supplements are added (see also Ashworth and Ferguson [3]). This table: Micronutrient powder or powdered complementary food supplements with fixed amounts of breastmilk and rice, and choice of fish, spinach, dhal, potato, onion, oil, or sugar, all with maximum intake.

Component	Diet without CFS	Diet + MN powder (5 MNs)	Diet + MN powder (16 MNs)	Diet + soy powder with MNs	Diet + MixMe Plus	Diet + TopNutri
Nutrients	% of proposed intake					
Protein	136	171	173	179	175	199
Vitamin A	***73***[a]	111	123	***74***	122	115
Vitamin E	***29***	***47***	***98***	***53***	***89***	100
Vitamin C	***53***	101	100	***43***	137	112
Thiamine	***77***	***87***	185	***93***	180	175
Riboflavin	***62***	***63***	137	***90***	140	168
Niacin	140	177	260	153	248	266
Vitamin B$_6$	***87***	***83***	156	***60***	144	153
Folic acid	139	159	157	100	187	149
Vitamin B$_{12}$	278	530	636	408	564	658
Pantothenic acid	117	127	127	122	208	249
Calcium	100	100	100	124	191	182
Phosphorus	103	122	123	104	129	176
Magnesium	***81***	***78***	***78***	***68***	***82***	131
Potassium	***98***	104	103	***91***	129	115
Iron (10% bioavailability)	***67***	203	172	125	100	152
Zinc (moderate bioavailability)	***32***	***73***	***66***	***61***	***57***	***66***
Copper	111	***88***	184	***68***	154	139
Manganese	483	452	453	425	483	556
Diet ingredients	Amount in diet (g)					
Breastmilk, 530 g	530	530	530	530	530	530
Rice, plain, boiled—minimum 150 g	150	150	150	150	150	150
Potato, cooked	56	62	58	0	0	0
Spinach, cooked—maximum 40 g	40	40	40	40	40	40
Onion	0	0	0	0	0	0
Lentil-dhal	80	8	12	39	80	40
Small fish with bones	15	16	16	0	19	21
Fish	0	91	91	127	46	70
Soybean oil	12	12	12	12	12	12
Gur-cane sugar	0	0	0	0	0	0
Supplement (g)		1	1	1	5	8

MN, micronutrient

[a] Nutrients for which less than 100% of recommended intake is achieved are displayed in bold italics.

young children (6 to 35 months) and to test its impact on phytate degradation and mineral bioavailability in this target group as well.

Ready-to-use foods vs. to-be-prepared foods: Storage and preparation

So far, we have considered the nutrient content, antinutritional factors, and specific ingredients of specially formulated foods for young, moderately malnourished children. Another important aspect to be considered is the form of these specially formulated foods that are provided as part of supplementary feeding programs, i.e., whether they are ready to use or need to be prepared, how easy and hygienic is their preparation, and how well they can be stored.

These aspects are important for any of the above-discussed options, whether referring to recommendations for foods prepared at home (i.e., germination, storing of fresh fish or meat) or to foods provided as food assistance (transport over considerable distance, storage, cooking fuel availability).

Foods that are ready to use are extremely convenient from the point of view of storage as well as preparation (which is not required) and consumption. Because they are very energy dense and contain very little water (to prevent growth of molds and bacteria), it is important

TABLE 5B. Micronutrient powder or powdered complementary food supplements with fixed amounts of breastmilk and rice, choice of spinach, dhal, potato, onion, oil, or sugar, all with maximum intake (i.e. no fish)

Component	Diet without CFS	Diet + MN powder (5 MNs)	Diet + MN powder (16 MNs)	Diet + soy powder with MNs	Diet + MixMe Plus	Diet + TopNutri
Nutrients	% of proposed intake					
Protein	***97***[a]	***97***	***97***	109	***97***	107
Vitamin A	***73***	109	122	***73***	122	114
Vitamin E	***28***	***28***	***79***	***28***	***79***	***91***
Vitamin C	***56***	103	103	***56***	150	118
Thiamine	***78***	***78***	176	***75***	176	166
Riboflavin	***57***	***57***	131	***85***	131	158
Niacin	106	106	189	100	189	186
Vitamin B_6	***87***	***87***	160	***83***	160	154
Folic acid	139	225	219	133	187	184
Vitamin B_{12}	***60***	***60***	166	***60***	166	166
Pantothenic acid	114	114	114	108	201	230
Calcium	***50***	***50***	***50***	125	129	111
Phosphorus	***67***	***67***	***67***	***63***	***67***	106
Magnesium	***72***	***72***	***72***	***69***	***72***	117
Potassium	***91***	***91***	***91***	***89***	125	100
Iron (10% bioavailability)	***64***	227	194	139	***96***	161
Zinc (moderate bioavailability)	***27***	***72***	***64***	***62***	***49***	***59***
Copper	108	108	204	103	166	149
Manganese	466	466	466	452	466	535
Diet ingredients	Amount in diet (g)					
Breastmilk, 530 g	530	530	530	530	530	530
Rice, plain, boiled – minimum 150 g	178	178	178	150	178	150
Potato, cooked	62	62	62	62	62	28
Spinach, cooked – maximum 40 g	40	40	40	40	40	40
Onion	20	20	20	20	20	0
Lentil-dhal	80	80	80	74	80	80
Soybean oil	12	12	12	12	12	19
Gur-cane sugar	0	0	0	0	0	0
Supplement (g)		1	1	1	5	8

MN, micronutrient

a. Nutrients for which less than 100% of recommended intake is achieved are displayed in bold italics.

that those who consume them have access to clean drinking water. Where the availability of cooking fuel or time for food preparation is limited, providing a RUF for an individual suffering from a special condition, such as a malnourished child, will be easier than providing a food that needs to be prepared separately from the family meal. In addition, a food that needs to be cooked specifically for one individual may be more likely to be shared with other family members.

The same advantage applies to biscuits or compressed bars, which are also ready to use. There is concern about using biscuits for complementary feeding because of the difficulty for consumers of distinguishing between nutritious and non-nutritious biscuits and the possible promotion of a habit of biscuit consumption, which may in fact lead to consumption of non-nutritious, high-sugar biscuits. However, when biscuits are used for feeding children with severe acute malnutrition (BP100), used as a short-term measure for reducing the risk of malnutrition under sudden situations of food insecurity (BP5), or used to feed children with moderate malnutrition for a limited period of time, these concerns do not apply. When designing biscuits as RUF, it is important to realize that baking

TABLE 5C. Lipid-based nutrient supplements with fixed amounts of breastmilk and rice, choice of fish, spinach, dhal, small fish with bones, potato, onion, oil, or sugar, all with maximum intake

Component	Diet + Nutributter (20 g)	Diet + Plumpy'Doz (45 g)	Diet + Indian RUFC (50 g)	Diet + Supplementary Plumpy (90 g)	Diet + Plumpy'Nut (90 g)
Nutrients	% of proposed intake				
Protein	135	127	111	***89***	***89***
Vitamin A	122	122	85	138	138
Vitamin E	***39***[a]	***91***	***54***	197	197
Vitamin C	***89***	***88***	***87***	109	109
Thiamine	118	157	***97***	129	129
Riboflavin	114	125	***87***	268	268
Niacin	178	183	140	100	100
Vitamin B_6	93	115	***76***	***89***	***89***
Folic acid	104	145	100	129	129
Vitamin B_{12}	421	346	326	256	256
Pantothenic acid	176	179	106	165	165
Calcium	100	122	100	***84***	***84***
Phosphorus	100	115	***71***	***69***	***69***
Magnesium	***69***	***87***	***74***	***63***	***63***
Potassium	***82***	***87***	***81***	***68***	109
Iron (10% bioavailability)	148	145	159	140	140
Zinc (moderate bioavailability)	***58***	***98***	***55***	121	121
Copper	***92***	100	102	296	296
Manganese	435	422	493	321	321
Diet ingredients	Amount in diet (g)				
Breastmilk, 530 g	530	530	530	530	530
Rice, plain, boiled—minimum 150 g	150	150	150	13	13
Potato, cooked	6	0	0	0	0
Spinach, cooked—maximum 40 g	40	40	40	5	5
Onion	0	0	0	0	0
Lentil-dhal	0	0	1	0	0
Small fish with bones	10	0	5	0	0
Fish	57	66	31	0	0
Soybean oil	12	0	0	0	0
Gur-cane sugar	0	0	0	0	0
Supplement	20	46	50	90	90

RUFC, ready-to-use food for children

a. Nutrients for which less than 100% of recommended intake is achieved are displayed in bold italics.

TABLE 5D. Lipid-based nutrient supplements with fixed amounts of breastmilk and rice, choice of spinach, dhal, potato, onion, oil, or sugar, all with maximum intake (i.e. no fish)

Component	Diet + Nutributter (20 g)	Diet + Plumpy'Doz (45 g)	Diet + Indian RUFC (50 g)	Diet + Supplementary Plumpy (90 g)	Diet + Plumpy'Nut (90 g)
Nutrients	% of proposed intake				
Protein	***97***[a]	100	***91***	***89***	***89***
Vitamin A	122	122	***85***	138	138
Vitamin E	***28***	***79***	***48***	197	197
Vitamin C	***89***	***88***	***88***	109	109
Thiamine	120	149	***97***	129	129
Riboflavin	112	124	***86***	268	268
Niacin	138	156	121	100	100
Vitamin B_6	***97***	119	***79***	***89***	***89***
Folic acid	173	187	132	129	129
Vitamin B_{12}	119	166	178	256	256
Pantothenic acid	170	171	103	165	165
Calcium	***67***	123	***86***	***84***	***84***
Phosphorus	***73***	100	***57***	***69***	***69***
Magnesium	***68***	***88***	***74***	***63***	***63***
Potassium	***79***	***84***	***80***	***68***	109
Iron (10% availability)	175	162	171	140	140
Zinc (moderate availability)	***59***	101	***55***	121	121
Copper	112	118	113	296	296
Manganese	448	443	500	321	321
Diet ingredients	Amount in diet (g)				
Breastmilk, 530 g	530	530	530	530	530
Rice, plain, boiled – minimum 150 g	150	150	150	13	13
Potato, cooked	6	3	0	0	0
Spinach, cooked – maximum 40 g	40	40	40	5	5
Onion	0	0	0	0	0
Lentil-dhal	0	46	36	0	0
Soybean oil	10	0	0	0	0
Gur-cane sugar	57	0	0	0	0
Supplement	12	46	50	90	90

RUFC, ready-to-use food for children

a. Nutrients for which less than 100% of recommended intake is achieved are displayed in bold italics.

biscuits at up to 200°C will destroy some of the heat-sensitive vitamins. Compressed biscuits, such as BP100 and BP5, do not have this problem.

For precooked dry foods that are to be prepared with water to make a porridge, boiling for 5 to 10 minutes is recommended in order to kill any microbes that could be in the water or the food. Instant foods that only require adding warm water are not preferred for use under less hygienic circumstances.

Current programs for moderately malnourished children

Tables 7 and **8** summarize the responses received to a questionnaire on current programs for moderately malnourished children that was sent to 10 UN agencies and donors, 20 international NGOs, 3 prominent pediatric associations, and 6 large national programs. The information included in this article pertains to the responses that included provision of a food supplement. For a more detailed description of the questionnaire, responses received, and information about programs providing dietary advice, see the article by Ashworth and Ferguson [3].

TABLE 6. Nutrient requirements proposed by Golden [1] compared with nutrients provided by corn–soy blend (USDA composition, see ref 29) with oil and sugar (3 times per day 35 g CSB + 3.5 g oil + 3.5 g sugar) combined with different complementary food supplements, consumed by 13- to 15-mo-old, breastfed, moderately malnourished child (7.4 kg, 851 kcal/day)

Component	CSB without CFS	CSB + MN powder (5 MNs)	CSB + MN powder (16 MNs)	CSB + soy powder with MNs	CSB + MixMe Plus	CSB + TopNutri	CSB + Nutributter (20 g)	CSB + Plumpy'Doz (45 g)	CSB + Indian RUFC (50 g)	CSB + Supplementary Plumpy (90 g)	CSB + Plumpy'Nut (90 g)
Nutrients	% of proposed intake										
Protein	112	112	112	123	112	127	106	100	***93***[a]	***90***	***90***
Vitamin A	140	176	189	130	189	177	166	136	***97***	137	137
Vitamin E	110	110	161	102	161	164	***90***	124	***91***	200	200
Vitamin C	***96***	143	143	***91***	190	164	130	112	111	110	110
Thiamine	126	126	***224***	117	***224***	***220***	163	172	122	131	131
Riboflavin	***98***	***98***	172	121	172	198	142	136	99	***268***	***268***
Niacin	170	170	***253***	158	***253***	***258***	195	185	150	102	102
Vitamin B_6	***81***	***81***	155	***75***	155	166	109	118	***80***	***89***	***89***
Folic acid	185	***271***	***266***	171	***233***	***227***	194	192	143	130	130
Vitamin B_{12}	179	179	***284***	168	***284***	***280***	***212***	***225***	235	260	260
Pantothenic acid	190	190	190	178	***278***	***315***	***237***	***204***	136	168	168
Calcium	195	195	195	***256***	***273***	***251***	179	190	149	***88***	***88***
Phosphorus	56	56	56	52	56	99	63	88	49	69	69
Magnesium	13	13	13	13	13	66	22	46	35	60	60
Potassium	24	24	24	24	58	48	37	49	***50***	***65***	107
Iron (10% bioavailability)	***233***	***396***	***363***	***291***	***266***	***324***	301	***238***	***245***	145	145
Zinc (moderate bioavailability)	51	96	88	84	***74***	***84***	***78***	109	***65***	121	121
Copper	179	179	***276***	166	***238***	***232***	181	156	151	***299***	***299***
Manganese	382	382	382	376	382	468	375	365	424	314	314
Diet ingredients	Amount in diet (g)										
Breastmilk	530	530	530	530	530	530	530	530	530	530	530
Soybean oil	10	10	10	9	10	10	8	5	5	0	0
Gur-cane sugar	10	10	10	9	10	10	8	5	5	0	0
Corn–soy blend	101	101	101	92	101	97	79	53	49	3	3
Supplement		1	1	5	5	8	20	45	50	90	90

CFS, complementary food supplement; MN, micronutrient; CSB, corn-soy blend.

a. Nutrients for which less than 100% or more than 200% of recommended intake is achieved are displayed in bold italics.

TABLE 7. Fortified blended food mixtures provided by organizations implementing supplementary feeding programs for children with moderate acute malnutrition

Organizations implementing and location[a]	No. of children/yr[b]	Corn–soy blend (g/day)	Oil (g/day)	Sugar (g/day)	Additional information
Action Contre la Faim (USA) East and Central Africa Tajikistan	42,000	180-200	20	20	Mixed before distribution. Target: 1,000 kcal/day. Also providing vitamin A capsules, iron/folic acid, mebendazole
Concern West Darfur Democratic Republic of the Congo)	16,500	200	20	20	In case of pipeline break of WFP, maize/soybean mixture purchased locally, but unfortified
Concern South Sudan	5,000	200	30	30	
Concern Niger	?	250	25	15	
Food for the Hungry Bolivia Democratic Republic of the Congo Kenya	57,000	400	31		
GOAL Ethiopia	?	277	33 mL		
GOAL Malawi	?	357			
Helen Keller International	40,000				
Niger		250	25	15	
Burkina Faso		200	20	15	
Mali		250	25	20	
Save the Children (UK) 6 African countries Afghanistan	30,000	Different ratios			

continued

The majority of programs provide fortified blended food, especially corn–soy blend, to moderately malnourished children, who are mostly wasted. **Table 7** shows the number of children reached with a mixture of corn–soy blend + oil + sugar by reporting programs. The total amounts to more than 550,000. Considering that many more programs are implemented, it can be estimated that at least 2 million moderately wasted children receive corn–soy blend (or wheat–soy blend) every year.

The majority of programs add oil and sugar to the fortified blended food, usually by mixing it with the food just before distribution (including oil reduces shelf-life), but sometimes by handing out the three commodities separately.* The ratio of corn–soy blend:oil:sugar varies, as was also observed in the Save the Children (UK) review of supplementary feeding programs by Navarro-Colorado [27]. On average, the ratio is 10:1:1, and approximately 1,000 kcal/day is provided.

Most organizations that answered the question on target intake from the corn–soy blend mixture for the malnourished child stated that this was 1,000 kcal/day (equivalent to 200 g of corn–soy blend + 20 g of oil + 20 g of sugar), while at the same time they said that they provided the corn–soy blend mixture as a take-home ration that was likely to be shared. Considering that the energy needs of a moderately malnourished 6.7-kg child 12 to 15 months of age with a weight gain target of 5 g/kg/day are 770 kcal/day and that many children also receive breastmilk, a target intake of 1,000 kcal/day from corn–soy blend is excessively high for many moderately wasted children and is also not possible to attain for a child who consumes three or four meals per day of 35 g dry weight each. However, unfortunately, little is known about actual intakes of corn–soy blend preparations by different age groups of moderately wasted children. Some programs provided family food rations or a supply of corn–soy blend for siblings to limit sharing of the corn–soy blend mixture that was provided to the moderately wasted child.

A number of organizations provided other kinds

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* UNIMIX (corn–soy blend provided by UNICEF) already contains sugar, usually 10% in exchange for corn.

TABLE 7. Fortified blended food mixtures provided by organizations implementing supplementary feeding programs for children with moderate acute malnutrition *(continued)*

Organizations implementing and location[a]	No. of children/yr[b]	Corn–soy blend (g/day)	Oil (g/day)	Sugar (g/day)	Additional information
GTZ–UNHCR Kenya	7,955	250	25	20	
International Rescue Committee—UNHCR Kenya	?	270 (UNIMIX)	25		UNIMIX already contains sugar. Target: 1,000–1,200 kcal/day
Médecins sans Frontières (Spain) Uganda	3,532	300	40	20	Reflects program June 2007–April 2008 Planned to change to RUFs in May 2008
UNHCR Djibouti	1,000	250	40	20	
UNHCR Uganda	2,000	229	29	29	
UNHCR Tanzania	2,671	120	20	20	Target: 1,000 kcal/day
UNICEF Niger	350,000	250	25	15	Families or siblings receive another ration, to maximize intake of the supplementary feeding ration by the target child. Target: 1,200 kcal/day Replaces other foods in the diet
Valid Ethiopia Sudan Zambia Malawi		Different ratios, depending on organization supported			

GTZ, Gesellschaft für Technische Zusammenarbeit; RUF, ready-to-use food; UNHCR, United Nations High Commissioner for Refugees

a. It should be noted that most of the corn–soy blend (or wheat–soy blend) distributed by the organizations listed below is donated either by the World Food Programme, which has received it from the United States or purchased it from local producers in a range of countries, or by UNICEF.

b. Most organizations provided the number of beneficiaries for supplementary feeding programs in 2007.

of food supplements (**table 8**). Some (reaching about 200,000 children) provided a mixture of fortified staple, pulse, oil, and sugar (UNICEF Uganda, Church World Service Indonesia, Bangladesh National Nutrition Program, and Action Contre la Faim Myanmar), some of which was locally produced, or BP5 (UNICEF Uganda). Some provided a supplement that also included milk and still had to be cooked, such as the fortified blended food mixtures (DREAM for HIV-positive children in African countries and GRET in Burkina Faso, Madagascar, and Vietnam). World Vision in Niger promoted home preparation of a local peanut paste mixed with dried moringa leaf concentrate for mildly malnourished children and provided the corn–soy blend mixture to moderately malnourished children (see **table 8** for details). A few organizations use lipid-based RUFs such as Supplementary Plumpy, Indian RUFC, peanut/soybean paste, Plumpy'Doz, or Plumpy'Nut for children with moderate acute malnutrition (Médecins sans Frontières, Action Contre la Faim WFP, Project Peanut Butter in Malawi) or even to prevent malnutrition [42]. A rough estimate of the number of children with moderate acute malnutrition receiving a lipid-based RUF is a maximum of 50,000 per year. Note that most lipid-based RUF is in the form of RUTF and is provided to children suffering from severe acute malnutrition.

Further programmatic considerations

Much of the discussions of this Consultation focused on the nutrient and food needs of individual malnourished children, which are a function of the percentage of lean body mass that they should gain and the desired weight gain, which are in turn dependent on the individual's nutritional status (stunted, wasted, or both) as well as on whether a specific food will be provided or whether the diet should be changed. However, from a programmatic point of view, it will rarely be feasible to really tailor the treatment to the individual moderately malnourished child.

In targeted programs that identify the individual malnourished (usually wasted) child, weight and height measures will be taken, a target for weight gain will be set, and the caretaker will be provided with dietary advice and complementary food supplements or special foods. The programs have no control over the diet consumed. Also, giving specific advice and different amounts of commodities to individual children depending on their needs is challenging, especially when working with community volunteers rather than medically or nutritionally qualified personnel or when workload is high. Furthermore, the number of different commodities and their quantities should be limited to reduce errors.

With the current development of new concepts and products for different types of malnutrition, many questions arise about what programs to implement or how to modify ongoing programs, and what advice or commodities to use. Although these program-related questions will be the subject of a follow-on meeting to be organized by WHO and partner organizations towards the end of 2009, some of them need to be answered now, even though it is clear that guidance is likely to change as more products and information about their use and impact become available. **Table 9** suggests response options that can be considered for food-assistance programs to prevent and treat moderate and mild child malnutrition (wasting, stunting). Which choice to make will depend on many factors, including:

» What is likely to have the best impact;
» Logistical considerations, such as the accessibility of the area and presence and capacity of implementing partners;
» Availability of preferred commodities within the desired time frame;
» Human capacity for designing, supervising, implementing, and evaluating the program;
» Funding for the program.

In situations of severe food insecurity where blanket supplementary feeding programs are implemented for young children and pregnant and lactating women, often also for reasons of logistics and safety, foods could be provided of which the composition is as recommended for treating moderate malnutrition, because these are designed to be inherently safe for nonmalnourished individuals. Because of the larger number of beneficiaries, blanket feeding of high-quality and more expensive food supplements comes at a higher commodity cost. However, at the same time, money is saved because there is no need to identify and follow individual moderately malnourished children.

Access to, affordability of, and distribution of specially formulated foods

Because treatment of severe acute malnutrition is considered a right of the child and is too costly for most families (about US$50 for one child's treatment with RUTF), it is generally provided by the public sector (governments or humanitarian agencies). For moderate malnutrition, however, the situation depends on the target group, the commodities, and the context.

For preventive purposes, complementary food supplements such as micronutrient powders, powdered complementary food supplements, and lipid-based nutrient supplements of 20 g/day or less, can be taken,with a product cost (subject to change) of US$0.02 to US$0.12/day. Although they should be used by the majority of children who consume too few animal-source foods and fortified complementary foods, they cannot be afforded by all households [43].

Ways are sought to target different socioeconomic groups in a country in different ways with the same product, which may be packaged differently for this purpose, so that wealthier households can cross-subsidize poorer households and public sector organizations can buy and distribute to the poorest. The use of vouchers for specific groups that are targeted for specific public programs is also considered [44].

Preventive or curative approach

Based on the successful treatment of severe acute malnutrition with RUTF, attention now focuses on the treatment of moderate acute malnutrition, the guidelines for which are similar to those for prevention of wasting and growth-faltering among children aged 6 to 23 months. Also, as explained by Golden [1], when treating children with moderate acute malnutrition, weight gain should be due mainly to increase in lean tissue and hence should also result in linear growth (note that many wasted children are also stunted). Among non-wasted children, it is better to prevent stunting between conception and 24 months of age than to treat stunting after it has occurred [45].

Thus, a good strategy for a population would be to focus on preventing malnutrition through programs that target pregnant and lactating women and children aged 0 to 23 months, and on treatment of moderate and severe wasting among children under 5 years of age. The former can also be considered treatment of a population; i.e., based on the prevalence of stunting among 2- to 5-year-olds, the younger children receive blanket treatment to reduce their risk of becoming malnourished. Ruel et al. [46] conducted a trial in which they compared two populations; in one population all children aged 6 to 23 months received a monthly supply of fortified blended food and oil, and in the other population all children aged 6 to 59 months suffering from moderate acute malnutrition received a monthly supply of the same. Three years later, the population levels of malnutrition were lower in the former than in the latter group, and the authors concluded that the former strategy was more effective for combating undernutrition.

What appropriate preventive measures are depends on the adequacy of the local diet, i.e., which dietary gap has to be filled, and on the accessibility of required foods. For treating moderate acute malnutrition, locally available foods can be used where accessible [3]. Where this option is not very feasible, processed and fortified

TABLE 8. Other foods provided to moderately malnourished children

Organizations implementing and location	Food ration provided, ingredients	Target group	Comments
UNICEF Uganda	Corn–soy blend + oil + sugar, or BP5 when these ingredients are not available	50,000–70,000 moderately malnourished children	
Church World Service Indonesia	Wheat–soy blend and recipes, with demonstration, such as cake, meatballs, etc., and fortified food from Kids Against Hunger, made of rice, soybean flour, dried vegetables, salt, maltodextrin, dextrose, hydrolyzed soy protein, soybean oil, and MNs	Children with moderate acute malnutrition on Nias and West Timor Islands	
BNNP Bangladesh	20 g roasted rice, 10 g roasted lentils, 5 g molasses, 3 mL oil (total 150 kcal)	91,435 children/yr, 150 kcal/day for underweight 6- to 11-mo-olds and 300 kcal/day for underweight 12- to 23-mo-olds	
Action Contre la Faim (France) Myanmar	Fortified mixture of 125 g rice, 125 g yellow beans, and 50 g sugar, with 43 g oil added just before distribution. Instant food, requires adding hot water. Locally produced	11,650 children/yr, moderately malnourished < 5 yr	A study was planned for 2nd half of 2008, to compare impact of this mixture with that of Plumpy'Doz and Supplementary Plumpy
World Vision Niger	3 different treatment groups receiving different foods under different schemes: Severe acute malnutrition: RUTF Moderate malnutrition: corn–soy blend (250 g) + oil (25 g) + sugar (15 g), referred to as "therapeutic food" Mild malnutrition: PD/Hearth + locally made food supplement Zogala Nut (leaf powder from *Moringa oleifera* [25%], peanut paste [55%], sugar [10%], peanut oil [10%], and iodized salt)	So far, in 2008: #12,929 < –3 Z scores (W/H < 70%) or MUAC < 110 mm # 1,167 –3 and –2 Z scores (70% < W/H < 80%) #560 –2 and –1 Z Scores (80% < W/H < 85%) and stunted All received MNs (vitamin A, iron/folic acid, zinc, vitamin C) 23,000 healthy children enrolled in growth monitoring	Depending on the amount of Zogala Nut consumed and the composition of the local diet, the foods consumed by the mildly malnourished may be of similar nutritional value as the corn–soy blend/oil/sugar diet The source of nutrient content of Zogala Nut has not been specified and is likely to vary because it is locally prepared (most MNs are from the leaf concentrate, i.e., no fortification) Numbers of mildly and moderately malnourished are very small compared with those with severe acute malnutrition
DREAM 9 African countries: all programs related to HIV/AIDS)	A variety of mixes, e.g., 70 g corn–soy blend/wheat–soy blend, 5 g oil, 8 g sugar, 25 g skimmed-milk powder	3,000 children who are HIV+ or born to HIV+ mothers/yr	

continued

TABLE 8. Other foods provided to moderately malnourished children *(continued)*

Organizations implementing and location	Food ration provided, ingredients	Target group	Comments
GRET in collaboration with IRD, Montpellier Madagascar Vietnam Burkina Faso	Developed complementary foods for feeding young children (6–23 mo) to prevent malnutrition Target population ~ 150,000 children. Recommended consumption 70–140 g/day from the following mixtures: Madagascar: maize, rice, soybeans, peanuts, sugar, salt, MNs, α-amylase Vietnam: rice, soybeans, sugar, milk powder, sesame, salt, MNs (produced by very-low-cost extrusion cooking) Burkina Faso 1: millet, soybeans, sugar, sesame, cowpeas, milk powder, salt, MNs, α-amylase Burkina Faso 2: millet, soybeans, peanuts, sugar, salt, MNs, α-amylase Burkina Faso 3: sorghum, millet, soybeans, sugar, peanuts, monkey bread, salt, MNs, α-amylase Burkina Faso 4: maize, soybeans, sugar, peanuts, milk powder, salt, MNs, α-amylase		GRET supports local enterprises to produce fortified infant food and to sell it to the poor at adapted price Note that 5 of 6 mixtures contain α-amylase (to reduce viscosity), 3 contain milk powder, and staple (maize, rice, millet, or sorghum) is the main ingredient in all. No studies available on impact
Project Peanut Butter Malawi	125 g peanut/soybean paste providing 75 kcal/kg/day and 1 RDA of all MNs. The paste is made from 25% whole roasted soybeans, 20% soybean oil, 26% peanut paste, 27% sugar, and 2% MNs	2,000 moderately malnourished children/yr	This has replaced the use of corn–soy blend, oil, and sugar in these operations
WFP Ethiopia Somalia Myanmar	Supplementary Plumpy, 90 g/day	Targeted distribution to moderately wasted children < 5 yr in Ethiopia and Somalia	
	Improved corn–soy blend with milk powder	Blanket distribution to children < 2 yr in Somalia	
	Indian RUFC + Plumpy'Doz	Blanket distribution to children < 2 yr affected by Myanmar cyclone	
Action Contre la Faim Sudan South Darfur	Supplementary Plumpy, 2 × 90 g/day	5,000 children in 2007, moderately wasted (WH ≥ 70% and < 80% and/or MUAC ≥ 110 and < 120 mm (6–18 mo old), only during hunger gap Jun-Oct 2007	Questionnaire response says that it is complementary to the diet, not a replacement However, it provides 1,000 kcal/day for 6- to 18-mo-old children (!)
Médecins sans Frontières (Suisse) Niger Sudan Somalia	2 sachets Plumpy'Nut/child/day, i.e., 1,000 kcal/day	10,000 moderately malnourished children/yr	This replaced the use of corn–soy blend, oil, and sugar in these MSF Suisse operations
Médecins sans Frontières (France) Niger	Children with moderate and severe acute malnutrition treated with Plumpy'Nut (2006) Blanket distribution of Plumpy'Doz during lean season (2007) as preventive measure	2006: 60,000 cases of moderate acute malnutrition and 5,000 of severe acute malnutrition	The preventive distribution in 2007 reduced case load of moderate acute malnutrition and severe acute malnutrition and limited the burden on health-care system of identifying and following malnourished individuals

BNNP, Bangladesh National Nutrition Program; GRET, Groupe de Recherche et d'exchange Technologiques; IRD, Institut de Recherche pour le Développement; MN, micronutrient; MUAC, mid-upper-arm circumference; PD/Hearth, Positive Deviance/Hearth Program; RDA, recommended dietary allowance; RUFC, ready-to-use food for children; RUTF, ready-to-use therapeutic food; WH, weight-for-height; WFP, World Food Programme foods or complementary food supplements can be made available through subsidies or for-free distribution. Such foods can be produced locally or imported, depending on ingredient availability, local producer capacity, and packaging facilities.

When specially formulated foods are used for treating moderate acute malnutrition, the results should preferably be obtained more quickly than when the diet is modified, because delivery of such products incurs program costs, and there is a greater expectation of the foods' being a treatment (the argument that the food is a treatment for the specific child should also prevent sharing with other household members). When treatment relies on dietary changes, it will hopefully result in a change of the diet of all young children in the family that is maintained for a longer period of time.

Discussion and conclusions

Many of the recommendations for dietary management of moderate malnutrition in children, including the use of specific food supplements, also apply to children aged 6 to 23 months who are at risk for becoming malnourished because they live in populations with a high prevalence of stunting as well as wasting. Therefore, most of what is discussed in this article is applicable to young children (6 to 23 months) as well as to moderately malnourished children (weight-for-height z-score < -2 and ≥ -3 or height-for-age z-score < -2).

Important foods for young and/or malnourished children include breastmilk, staples (for energy and some micronutrients), animal-source foods (good sources of protein, minerals, and some vitamins), legumes or lentils (particularly for protein), vegetables and fruits (for vitamins, minerals, and vitamin C to enhance nonheme iron absorption), oil (for energy and essential fatty acids), and a source of iodine such as salt (but high sodium intake in moderately malnourished children is not desirable). Particularly important components of the diet are protein quality, essential fatty acid content, bioavailability of micronutrients, and limited antinutrient content, as well as high energy and nutrient density.

These requirements are difficult to fulfill when a diet includes few animal-source foods and fortified foods. A largely plant-based diet with few fortified foods is disadvantageous, because of a relatively high content of antinutrients, lower bioavailability of certain micronutrients (iron, vitamin A), and the lack of specific nutrients and active compounds contained in animal-source foods. Breastfeeding is an important source of several nutrients, but also needs to be complemented by animal source foods and fortified foods.

When the diet is largely based on plant sources, three main options can be considered for modification or development of food commodities for young or moderately malnourished children:

» Improving the current standard of fortified blended foods by reducing phytate content by dehulling and/or degerming of corn and soybeans, improving micronutrient premix specifications, and adding milk powder, sugar, and oil;

» Modifying the RUTF recipe to develop RUSF (ready-to-use supplementary food) using local foods as much as possible and limiting costs, for example, by reducing milk content, replacing some dairy protein with soy protein (extracts), using chickpeas or sesame instead of peanuts, and making biscuits or bars instead of a lipid-based food;

» Development of complementary food supplements that add the nutrients, ingredients, and active compounds to diets that are not contained in adequate amounts.

Different categories of complementary food supplements can be distinguished, ranging from micronutrient powder, powdered complementary food supplements of protein, amino acids, and/or enzymes and micronutrients, to lipid-based nutrient supplements that range from 20 to 90 g/day (120 to 500 kcal/day) and typically contain milk powder, essential oil, peanut paste, sugar, and micronutrients. Some complementary food supplements are primarily used for prevention of malnutrition (≤ 20 g/day), whereas others (≥ 40 g/day) are used for blanket or targeted supplementary feeding of malnourished individuals or populations with a high prevalence of malnutrition.

Although we know what nutrients are required, which antinutrient contents should be reduced, and what foods should ideally be used, choosing effective, available, appropriate, and cost-effective foods is a challenge. This is due to a number of factors, including the following:

» The fact that as yet, only a few of the above-mentioned specially formulated foods and food supplements have been assessed in terms of their impact on recovery from moderate malnutrition, i.e., length and weight gain, functional outcome, immunity, and micronutrient status. Thus, there is an urgent need for studies that determine the impact of new or modified foods for treating moderate malnutrition in comparison to fortified blended foods and RUTF;

» The availability of RUTF is limited, and it is preferentially used for treating severe acute malnutrition;

» Milk appears to be an essential food that comes at a relatively high cost compared with staples and soybeans;

» The need for high-quality, nutritious foods for young children is not yet understood by all development partners, which limits commitment and funding.

Also, many of the modified or new foods or complementary food supplements are a new concept, both for consumers and for program implementers; thus, experience with their introduction, distribution, and

TABLE 9. Current response options for food-assistance programs to prevent and treat moderate and mild child malnutrition (wasting, stunting)

Intervention	Potential target groups	Considerations
Blanket supplementary feeding where the prevalence of malnutrition is high, i.e., ≥ 30% underweight or ≥ 15% wasted among children < 5 yr	All young children, especially those < 2 yr	Blanket supplementary feeding of all children < 2 yr is probably more effective than targeted supplementary feeding of underweight children < 5 yr [43]. When possible, improved fortified blended foods (which have better MN profile and, when possible, include milk powder, sugar, and oil) should be used. Alternative to be explored: staple for general population with additional complementary food supplements that provide 250–500 kcal for children 6–23 mo or 6–35 mo of age
Targeted supplementary feeding (appropriate where blanket feeding is not necessary due to lower malnutrition prevalence)	Children < 5 yr with moderate acute malnutrition	RUTF (500 kcal/day), new RUF commodity (500 kcal/day), complementary food supplements (250 kcal/day) + staple, improved fortified blended food with skimmed-milk powder, oil, and sugar, or standard fortified blended food mixed with sugar and oil
Home fortification using complementary food supplements such as MN powder, lipid-based nutrient supplements, and powdered complementary food supplements	Young children (< 5 yr) who cannot meet their needs from the general food ration or from the local diet that is within their means (i.e. available, affordable, acceptable)	Home-fortification commodities can be used when the quality of the primary diet is insufficient. Depending on the age group, prevailing malnutrition rate, and diet, a selection of the most appropriate complementary food supplements can be made
Cash transfers or vouchers to obtain nutritious foods or complementary food supplements	Vulnerable households in settings where food is available in markets and capacity for implementing programs exists	May be particularly suited for urban and periurban areas. To maximize impact on nutrition, collaboration with private sector should ensure availability of specific nutritious commodities to which the vouchers provide access. Eligibility for receiving a voucher can be linked to conditional cash transfer or food-for-work programs. Collecting vouchers and reimbursing shopkeepers requires reasonably functioning markets and administrative systems [44]

MN, micronutrient; RUF, ready-to-use food; RUTF, ready-to-use therapeutic food

use needs to be built.

It is important to note that the nutrient densities proposed by Golden [1] for specific nutrients are based on the assumption that the densities for other nutrients are also realized. For example, a higher intake of zinc than the RDA could affect copper metabolism except when copper intake is increased concurrently. Thus, when diets, with or without inclusion of special foods or complementary food supplements, meet the proposed requirements for some but not for other nutrients, this may have negative consequences for the status of the nutrient(s) of which too low amounts are consumed.

Recommendations

In order to move forward with the development and use of special food commodities for young and/or malnourished children, steps need to be taken in the following areas:

Use of new products

With the increasing development of products for preventing or treating different forms of malnutrition, there is a need for guidance on expected impact and on when, how, and for whom they can be used. The Consultation agreed that if it is expected that a new commodity has a better impact than currently used fortified blended food, it can be used in programs, provided that the product is acceptable to the beneficiaries, while at the same time its impact is studied under controlled circumstances (which could be in another location). Programs that use a new product should collect data to monitor the time needed for recovery of children with moderate malnutrition, when the product is used for treatment, or on the occurrence of new cases of malnutrition if it is used for prevention. Preferred comparison treatments for a study under controlled circumstances are the current fortified blended foods and RUTF; the latter is an adequately fortified, nutrient-rich therapeutic food. Outcome indicators should include indicators of physiological, immunological, cognitive, and body compositional recovery as well as simple weight gain (see also the Proceedings of the Consultation [47]).

Product development

Urgent questions and issues to be addressed for the development of new foods and complementary food supplements include the following:

- How much milk is required for optimal growth at different ages?
- Could a different combination of nutrients and active compounds achieve the same effect as milk powder?
- The use of phytase for human consumption needs to be permitted for young children also, and its impact on mineral bioavailability and digestibility should be assessed.
- The contents and effects of specific antinutrients need to be determined
- Food-composition tables need to include the contents of a wider range of micronutrients, active compounds, including fibers, and antinutrients.

Way forward for programs

Programs need to be adapted based on the newly proposed nutrient requirements for moderately malnourished children [1], the use of existing ingredients [2], the development of new foods and complementary food supplements (this article), improved understanding about which dietary changes to recommend and how [3], and increasing experience with production and use of new products in existing or modified programs. The following are some program-related issues that will need to be addressed in the near future:

- How can production capacity for new, especially ready-to-use, products be increased?
- How can the public and private sectors collaborate more effectively with regard to product development, production capacity, and distribution?
- Although the *why* of improved nutrition programming for young and for moderately malnourished children is clear, and the most suitable dietary options for different contexts are becoming clear, much experience needs to be gained with *how* to advocate for, design, and implement modified programs. This involves issues such as the following:
  - Advocacy at global and national levels about why modification of programs and commodities is proposed;
  - Program design: exchanging commodities or modifying programs?
  - Acceptability and awareness of new commodities among communities;
  - How are very similar commodities that are simultaneously distributed, such as corn–soy blend for general use and corn–soy blend with milk for young or malnourished children, used at the household level?
  - Can RUF for an individual child be provided with staples for general use by the family or should the RUF ration be doubled?
  - Evaluation of program data about the use and impact of new products.

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Proceedings of the World Health Organization/UNICEF/World Food Programme/United Nations High Commissioner for Refugees Consultation on the Management of Moderate Malnutrition in Children under 5 Years of Age

Jeremy Shoham and Arabella Duffield, Rapporteurs

Introduction

Moderate malnutrition includes all children with moderate wasting, defined as a weight-for-height between −3 and −2 z-scores of the World Health Organization (WHO) child growth standards, and all those with moderate stunting, defined as a height-for-age between −3 and −2 z-scores of the WHO child growth standards [1]. Most of these children will be moderately underweight (weight-for-age between −3 and −2 z-scores). Moderate malnutrition affects large numbers of children in poor countries, placing them at increased risk of mortality. A recent analysis of data from 388 national surveys from 139 countries from 2005 has provided an estimate that about 36 million children aged 6 to 59 months are suffering from moderate wasting. Approximately 178 million are estimated to be stunted [2]. Moderate malnutrition increases the risk of death from common diseases and, if not adequately treated, may worsen, resulting in severe acute malnutrition (severe wasting and/or edema) and/or severe stunting (height-for-age < −3 z-scores), which are both life-threatening conditions. Therefore, the management of moderate malnutrition is a public health priority.

In contrast to severe malnutrition, programs for the management of moderate malnutrition in children have remained virtually unchanged for the past 30 years, although it seems likely that this form of malnutrition is associated with a larger proportion of nutrition-related deaths than severe malnutrition.

WHO convened a meeting in Geneva from 30 September to 3 October 2008 to address this problem. The overall aim of the meeting was to answer the question "What diets should be recommended to feed moderately malnourished children?"* The general objectives of the meeting were to identify areas of consensus on the nutrient needs and dietary management of moderate malnutrition in children that can be translated into evidence-based global guidelines, and to identify knowledge gaps that should be addressed by research, both in the area of dietary management and in the modalities for providing that diet.

The specific objectives of the meeting were:

- To provide an estimate of the nutritional requirements of children with moderate malnutrition, examining wasted and stunted children separately;
- To examine current approaches for the management of moderate malnutrition, based either on dietary counseling or on the provision of food supplements;
- To formulate recommendations to improve the dietary management of moderate malnutrition.

The expected outcomes of the meeting were:

- Preliminary recommendations for the management of moderate malnutrition, with a detailed research agenda to generate evidence needed to strengthen these preliminary guidelines;
- Recommendations for feeding children with moderate malnutrition for the Codex Alimentarius working group developing standards of food products for underweight children.

In the absence of specific recommendations, it was also assumed during this meeting that children with severe stunting would benefit from a diet adapted for moderately stunted children and that children suffering from growth faltering would benefit from a diet adapted for wasted or stunted children, depending on the nature of their growth deficit.

In absence of a strong evidence base to make

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This report contains the collective views of an international group of experts and does not necessarily represent the decisions or the stated policy of the World Health Organization.

* Another WHO consultation is planned to review the evidence on strategies and programmatic approaches to managing moderate malnutrition that aims to answer questions not addressed in this meeting.

recommendations in many areas related to the management of moderate malnutrition, the Consultation was the start of a process of developing guidance in this area. Recommendations made in this report only reflect the participants' opinions and should not be regarded as formally endorsed by WHO. For the time being, research organizations are encouraged to fill the knowledge gaps identified in this meeting so that recommendations can soon be developed based on solid evidence.

Four background papers were commissioned by WHO in advance of the meeting and circulated among the participants. In addition to these background papers, a call for abstracts was circulated to a large number of agencies implementing programs or carrying out research on the management of moderate malnutrition. During the meeting, authors were asked to present key elements of their initiatives to improve the management of moderate malnutrition.

The presentations were followed by discussions and working group sessions to develop consensus statements and identify areas for research on the improved dietary management of moderate malnutrition. The consensus statements, discussion, and research are presented below under four central themes related to the contents of the four background papers.

Nutrient content of diets suitable for feeding moderately malnourished children (Paper 1)

This background paper (prepared by Mike Golden, Emeritus Professor, Aberdeen University) provides tentative recommendations for diets suitable for feeding children with moderate malnutrition, expressed in nutrient densities per 1,000 kcal.

The paper examined separately requirements of type I and type II nutrients. Type 1 nutrients are those whose deficiencies translate into characteristic clinical symptoms associated with the dysfunction of a particular biochemical pathway. Type II nutrients are those needed for the growth of lean tissues. Tentative recommendations for the quantities of type I nutrients needed by children with moderate malnutrition were based on the need to replenish body stores and to re-establish the compromised biochemical function, taking into account additional needs resulting from an increased exposure to stress and infections. Tentative recommendations of intakes of type II nutrients were made based on a factorial method, taking into account the expected lean tissue deposition and possible malabsorption. The estimations of type II nutrient requirements were based on theoretical optimal weight and height gains, acknowledging that these weight and height gains are rarely observed in practice. The paper also discussed the role that antinutrients play in determining the absorption of both type I and type II nutrients and emphasized that the recovery of children with moderate malnutrition should not be judged only on the basis of weight gain. A high weight gain can be related to an increase of fat tissue, with an inadequate restoration of lean body mass and physiological functions. In this regard, height gain that is accompanied by an increase in lean body mass is a better indicator of recovery than weight gain. It is important to examine body composition and other physiological functions, such as immunological functions and cognitive development, when evaluating the efficacy of a new diet. To achieve optimal growth and full functional recovery, it is essential to provide all nutrients needed by children with moderate malnutrition. Approaches putting emphasis on single nutrients are misguided and should be abandoned.

The presentation by Nigel Rollins (WHO) on managing the needs of HIV-infected children emphasized how little is known about the relationship between HIV and moderate malnutrition in infected children and how there is currently no basis for recommending different nutritional management for these children, apart from increased energy intake, as compared with non-HIV-infected children. The current WHO Guidelines on Integrating Nutrition into the Care of HIV-Infected Children [3] utilize experiences and practices from caring for HIV-uninfected children with growth faltering and some basic knowledge of the relationship between HIV disease progression and nutritional status. However, there are still a number of research areas where comparative trials are needed to determine optimal care and interventions.

A presentation by Mark Manary (St. Louis Children's Hospital) on recent attempts to supplement the diet of children with moderate malnutrition to prevent kwashiorkor in Malawi highlighted the lack of an evidence base to make specific recommendations for the dietary management of moderate malnutrition in children in areas of high kwashiorkor prevalence. The presentation made clear that fundamental research to better understand the pathophysiology of kwashiorkor is needed to improve current programs in these areas.

After the discussion and working group sessions that followed these presentations, the participants agreed on the following statements about diets suitable for feeding moderately malnourished children:

- The nutritional requirements of moderately malnourished children probably fall somewhere between the nutritional requirements for healthy children and those for children with severe acute malnutrition during the catch-up growth phase.
- The nutrient intakes of moderately malnourished children need to be adequate to allow wasted children to synthesize the lean tissue deficits and to allow stunted children to achieve both accelerated linear growth and associated accrual of lean tissue.

Whereas most previous research has focused on the rehabilitation of severely wasted and/or edematous children, there is some evidence that stunted children can also recover previous deficits in linear growth. However, there is less research available to document the extent and velocity of such recoveries of linear growth and the related nutritional needs. It is uncertain also whether improved linear growth during rehabilitation is associated with recovery of other deficits, such as cognitive deficits associated with stunting.

» Diets with a nutrient density equivalent to that of F100 and a low antinutrient content, provided at an energy intake to support the desired rate of weight gain, are adequate to promote height and weight gain and may also be effective at restoring functional outcomes, including physiological and immunological function toward normal, in moderately wasted children. However, diets with a lower density of some nutrients, notably potassium and zinc, may also accomplish these goals.

» Some nutrients can interact; for instance, iron can limit the effects of zinc, an excess of zinc can induce a copper deficiency, and a magnesium deficiency can have an effect on potassium retention. Attention should be given to these possible interactions when deciding about fortification levels.

» Diets with a nutrient density in relation to energy equivalent to that of F100 have been used without apparent adverse effects on hundreds of thousands of children with severe acute malnutrition and compromised physiological functions. They are unlikely to have adverse effects on moderately wasted children. However, there are insufficient data to show whether the resulting tissue deposition and body composition are optimal.

» Energy requirements of moderately malnourished children increase in relation to the rate of weight gain during catch-up growth. Energy requirements also depend on the type of tissue deposition, as 1 g of fat tissue requires about 8 kcal/g for synthesis, in contrast to 1.8 kcal/g for lean tissue. A low weight gain in relation to energy intake may be due to preferential fat deposition as a result of an inadequate supply of nutrients needed for the accumulation of lean tissue.

» Wasted children can put on weight (recover) at a rate of 5 g/kg/day or more. This may require an additional 25 kcal/kg/day or more, in addition to an adequate "base" diet.

» For stunted, nonwasted children, height gain should be associated with some weight gain to maintain weight-for-height. This associated weight gain, comprising lean and fat tissue, should be taken into account when estimating energy and nutrient requirements of these children. It is not sufficient to provide them with only the additional nutrients needed for bone growth.

» There is evidence that growth deficits can be treated (i.e., that catch-up growth for height can occur) in children far beyond 2 years of age and even in adolescents, provided that a high-quality diet is sustained, though there is no evidence of similar recovery of other deficits associated with stunting, such as cognitive deficits. However, the prevention of stunting should always be directed at the window of opportunity from conception to the first 24 months of life, when most growth faltering occurs and impacts on health and brain development are greatest.

» Consumption of excess energy by wasted and stunted children, without the provision at the same time of all nutrients needed for an appropriate rate of lean tissue synthesis, will lead to the synthesis of excess fat tissue, with limited health benefits or even negative health effects.

» Currently, there is no evidence that rapid lean body mass growth of children under the age of 2 years has any serious negative long-term consequences.

» There is no physiological advantage in having more than 10% of energy derived from proteins to promote recovery of moderately wasted children. Higher protein intakes will increase renal solute load and may also have a negative effect on appetite. As a consequence, the participants concluded that it is not advised to use diets providing more than 15% of energy as protein in moderately wasted children.

» Catch-up in height is a less anabolically intense process than catch-up in weight, and correction of stunting requires less protein for tissue deposition than correction of wasting. However, as mentioned in the 2007 WHO report on protein requirements, having a protein intake higher than that needed for tissue deposition may have an additional positive effect on linear growth through a hormonal effect [4]. This possibility, however, is based on theoretical considerations and has not been verified in practice. Milk, unlike other protein sources, does appear to stimulate insulin-like growth factor 1 (IGF-1) secretion, but there is no clear information on the amount of milk that is needed to have this effect nor on its practical importance. On the other hand, high-protein diets increase renal solute load and, in the case of plant-based diets, are associated with high levels of antinutrients. For these reasons, the participants thought it is probably unnecessary to provide more than 12% of energy as protein and unadvisable to use diets providing more than 15% of energy as protein.

» Proteins used to feed moderately malnourished children should have a PDCAAS* of at least 70%. Giving

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* PDCAAS (protein digestibility-corrected amino acid score) is a method of evaluating the protein quality based on the amino acid requirements of humans.

lower amounts of proteins with higher PDCAAS may be advantageous.

- The diets of children recovering from moderate wasting should provide at least 30% of their energy as fat. A higher percentage of energy derived from fat (35% to 45%) might have advantages, provided the density of nutrients is adequate.
- The participants recommended that diets for moderately malnourished children have at least 4.5% of their total energy content from n-6 polyunsaturated fatty acids (PUFAs) and 0.5% from n-3 PUFAs. The participants advised that the ratio of linoleic/α-linolenic acid should remain in the range of 5 to 15. A ratio within the range of 5 to 9, however, may be preferable.
- When large quantities of nutrients known to have an effect on acid–base metabolism are added to foods, their potential effect on the acid–base balance of the body after being absorbed and metabolized should be estimated. Their overall effect should remain neutral. Magnesium and calcium salts containing well-absorbed anions (such as chloride) should be avoided, as they may induce acidosis; organic magnesium and calcium salts, such as citrate, are preferable. Minerals added to the diet should preferentially be in a soluble form.
- The energy needs of moderately malnourished HIV-infected children are increased by 20% to 30% in comparison with those of non-HIV-infected children who are growing well. There is no evidence for increased protein requirements in relation to energy; i.e., 10% to 15% of the total energy intake is sufficient, as for non-HIV-infected children with moderate malnutrition
- Micronutrient intakes at the Food and Agriculture Organization (FAO)/WHO-recommended nutrient intake (RNI) levels need to be assured in HIV-infected children through consumption of diversified diets, fortified foods, and micronutrient supplements as needed. WHO recommendations for routine vitamin A supplementation (Integrated Management of Childhood Illness [IMCI]) and vitamin A supplementation in children who have signs of vitamin A deficiency and zinc supplements in children with diarrhea remain the same for HIV-infected children.
- As with children who are not HIV infected, when energy intake is increased, this should be matched by appropriately increased intakes of type I and type II nutrients.

Research needs

It is unclear whether a diet adequate for treating a moderately wasted child will also be adequate to treat a stunted child. It is possible, for example, that the stunted child will require a diet with a higher density of those nutrients specifically needed for cartilage formation and bone growth, such as sulfur and phosphorus. The length of time required for catch-up growth is also not known. Wasting may be corrected in a few weeks with an adequate diet, but the correction of stunting may take longer. There are data to suggest that children need to have an adequate weight-for-height before growing in height. Other data suggest, however, that children consuming a diet providing large quantities of all nutrients needed for linear growth may grow in length before reaching an adequate weight-for-height. Further studies are needed to clarify the effect of the diet on the timing of linear growth in relation to weight gain. This would be facilitated by the development of reliable techniques to measure length gain over short periods of times in the field.

Research is also needed on safe upper limits of different nutrients at different ages, as well as the requirements and importance of specific and often “forgotten” nutrients such as potassium, sulfur, phosphorus, and selenium. Some of these nutrients are not well recorded in international nutrition databases and hence may not be taken into account in calculations of dietary adequacy.

More field-friendly techniques (such as blood-spot technology) for assessing deficiencies of certain type I nutrients are needed. This will help build up knowledge of the prevalence of type I nutrient deficiency diseases. There is also a need for research on potential non-anthropometric outcome measures for assessing the efficacy of products and interventions for addressing moderate malnutrition.

Research is required to better understand the pathophysiology of how HIV causes undernutrition, how HIV-related undernutrition differs from undernutrition due to other causes, and how to distinguish between the different etiologies. Moreover, results from comparative studies of different nutritional interventions to treat children with HIV and undernutrition are needed.

Fundamental research is needed to obtain a better understanding of the pathophysiology of kwashiorkor. Currently, none of the proposed mechanisms for the development of kwashiorkor are supported by strong evidence that can be translated into preventive programming.

Foods and ingredients suitable for use in moderately malnourished children (Paper 2)

This background paper (prepared by Professor Kim Michaelsen and colleagues from the University of Copenhagen and Professor Tsinuel Girma from the University of Jimma, Ethiopia) provides an extensive description of foods and ingredients most commonly used to feed children with moderate malnutrition. It highlights the special values of animal-source foods, which usually have a high content of type I and type II nutrients and are virtually free of antinutrients, thereby making the nutrients more bioavailable. Such foods also do not contain any dietary fiber. Moreover, dairy products can have a specific effect on growth through the stimulation of IGF-1 secretion. In addition to animal-source foods, vegetable fats are useful to provide adequate quantities of essential fatty acids.

Elaine Ferguson (London School of Hygiene and Tropical Medicine) presented a short paper explaining how linear programming can be used to check the nutritional adequacy (and assess the cost) of diets recommended for children with moderate malnutrition. Currently, there are various mathematical tools available, or under development, which determine whether it is possible to design a diet that is compatible with local feeding habits and provides all nutrients needed for growth. Linear programming can be used to design optimal diets that deviate as little as possible from current diets. Another approach is to use simulation techniques whereby software programs randomly generate thousands of diets complying with tentative feeding recommendations. The nutritional composition of these diets is then examined.

After the discussion and the working group sessions that followed the presentations, the participants agreed on the following points:

- The addition of animal-source foods to a plant-based diet promotes the recovery of moderately malnourished children. Diets providing substantial quantities of animal-source foods, including dairy products, provide high-quality protein and bioavailable micronutrients and have low levels of antinutrients and fiber.
- Diets based exclusively on plant foods need to be fortified and processed in such a way as to remove antinutrient contents to allow normal growth of well-nourished children under the age of 2 years. It may be also advantageous to reduce the level of dietary fiber, but this remains unproven.
- Diets with low antinutrient and fiber contents are beneficial for promoting the recovery of malnourished children.
- Processed fortified plant-based foods with a high PDCAAS, low levels of antinutrients, and low fiber content may also be used to treat moderately malnourished children, but this needs further testing.
- Phytate may seriously limit the efficacy of plant-based foods. The possibility of safely reducing phytate content by the use of phytase and/or food processing should be explored.
- Highly refined cereal flours (those with low extraction rates) have lower levels of antinutrients and dietary fiber than less refined flours. Highly refined flours cost more and have lower vitamin and mineral levels — although these vitamins and minerals are more bioavailable.
- Blended flours prepared with dehulled legumes are preferable to those prepared with whole legume flour.
- Food-processing techniques, including home-based processing techniques such as fermentation and soaking, can improve food quality, specifically nutrient bioavailability. The effect of antinutrients in complementary foods based on the family diet can be decreased by various traditional food-processing methods, such as malting or soaking. The feasibility and efficacy of these processing techniques for the management of moderate malnutrition should be assessed.
- The manufacturers should make available information about important antinutrients and the fiber content of the food produced to treat or prevent malnutrition in children.
- There may be some benefit in increasing the energy density of semisolid foods, such as porridges, to promote rapid weight gain of recovering malnourished children.
- The energy density of semisolid foods can be increased by reducing the water content or by adding fat or sugar. Adding fat and sugar, however, decreases the nutrient density in relation to energy and is acceptable only if the overall density of each and every essential nutrient is sustained at a level that supports normal balanced tissue synthesis.
- The increase in viscosity resulting from the reduced water content can be limited by using amylase or amylase-rich flours.
- Foods with a high energy density often have a high renal solute load and may not provide enough water for recovering children. Renal solute load is related to the protein and mineral contents of the diet. On the other hand, it is not related to dietary carbohydrate (including sugar) or fat content.
- Children fed diets with a high solute load in relation to their water content may need additional water during and between meals. Breastfeeding provides large quantities of water, in addition to a full range of nutrients. Breastmilk has a low solute load, and consumption of breastmilk rather than water should always be encouraged when energy-dense foods are provided.
- Because most diets in poor countries have a low level of n-3 (omega-3) fatty acids and an inappropriately high ratio of n-6 fatty acids to n-3 fatty acids, foods with high n-3 fatty acid contents should be promoted. These include soybean and rapeseed oil and fatty fish or its products. This is especially important for nonbreastfed children, since breastmilk usually provides large quantities of n-3 essential fatty acids. The essential fatty acid composition of breastmilk, however, is also dependent on the mother's intake of

essential fatty acids and may be low in case of insufficient maternal intake.

- The source and amount of fat used in processed foods for moderately malnourished children must be declared.
- The sodium level should be kept at a minimum in foods given to moderately malnourished children. It is not necessary to add salt to foods for moderately malnourished children.
- The iron content in fortified foods should be kept at levels needed to prevent iron deficiency. The goal is to achieve age-appropriate, adequate iron intake over the course of the day; no attempt should be made to add quantities of iron needed to treat iron-deficiency anemia to foods, especially in areas where malaria is prevalent or where kwashiorkor may occur.

Research needs

There is uncertainty about the minimum quantities or types of animal-source foods that are needed in the diets of children with moderate malnutrition. Milk and, potentially, eggs seem to have advantages over meat and fish in terms of growth but not in terms of improving micronutrient status. It is unclear whether children who are stunted but not wasted may benefit from different proportions of animal:plant protein in their diets, as compared with diets designed to treat wasting.

Research is also needed to assess whether dairy products, including whey, stimulate linear growth and/or reverse wasting in malnourished children in comparison with plant-based foods (e.g., soybeans) with high PDCAAS, low levels of antinutrients, and low fiber contents. The extent to which cooking or heat treatment denatures bioactive components of dairy products should also be investigated.

Data are needed on the maximum acceptable levels of intake of the most important antinutrients and of different types of fibers for children with moderate malnutrition. There is also a need to establish upper acceptable limits for sodium and iron contents of foods for children with moderate malnutrition.

Research is also needed on how to optimize the energy and nutrient density of foods while minimizing costs. There is also a need to establish whether high energy density of diets or the use of sweet supplements may cause acceptability problems in the short or the long term and run the risk of displacing the less energy-dense or less appetizing local diets.

More information on the importance of the quality of fat (i.e., optimal essential fatty acid and PUFA ratios) is required.

Dietary counseling for moderately malnourished children (Paper 3)

This background paper (prepared by Professor Ann Ashworth of the London School of Hygiene and Tropical Medicine) concluded that mothers of children with moderate malnutrition are usually given the same general dietary advice as mothers of well-nourished children. None of the programs reviewed gave guidance about quantities of nutrient-dense foods that are needed for the recovery of children with moderate malnutrition. The paper suggested that the generic dietary recommendations developed by WHO and FAO for well-nourished children may meet the requirements of children with moderate malnutrition if the recommendations are made more specific and context appropriate.

To date, there have been few studies of the efficacy of dietary counseling in treating moderate malnutrition. Studies looking at dietary counseling for moderate malnutrition report very different weight gains. Little information is available on other outcomes. Even height gains are rarely reported. Differences in reported weight gain are probably due to differences in initial nutritional status (stunted vs. wasted). It was noted that one of the most effective pilot nutrition counseling programs implemented in Bangladesh provided micronutrient supplements that may have increased its efficacy.

FAO has been developing materials for the use of local foods for feeding children during the complementary feeding period. These materials could be applicable in the context of moderate malnutrition. Their efficacy, however, has never been formally tested.

Save the Children US presented data showing that large-scale positive deviance programs in Vietnam and other countries have not had a significant impact on reducing moderate malnutrition.

After the discussion and the working group session that followed the presentations, the participants agreed on the following points:

- Dietary counseling, when done well, can be effective in preventing and managing moderate malnutrition. Prevention of linear growth retardation is best addressed prenatally and during the first 2 years of life.
- Dietary counseling for the prevention and management of malnutrition in general is often weak or absent and should be strengthened for all caregivers, especially those of children aged less than 24 months. Capacity-building of health care providers in dietary counseling is essential.
- Dietary counseling, breastfeeding counseling, and improving feeding practices should always be part of the management of moderate malnutrition. This is essential even when food supplements are given.
- Formative research should always be carried out

before formulating dietary recommendations. Only foods and feeding practices that are affordable, feasible, and acceptable to families should be recommended.

- Caregivers of children with moderate malnutrition need a reinforced approach for dietary counseling, including demonstrations, home visits, and/or group meetings. Dietary counseling for children with moderate malnutrition should specifically reinforce the quantity of nutrient- and energy-dense foods that are needed for recovery and promote age-appropriate feeding practices that are needed for recovery. Providing caregivers with standard nonquantitative recommendations designed for healthy children is likely to be insufficient.
- The nutritional adequacy of diets based on family foods should always be checked when planning strategies to treat children with moderate malnutrition. As a strict minimum, recommended diets should aim to provide all nutrients at the level currently recommended by FAO and WHO for healthy children, but a higher nutritional density would be preferable.
- Where prior assessment indicates that it is not possible to provide all nutrients needed by the child using the accessible family foods, other approaches, (including the use of fortified foods, food supplements, or micronutrient supplements) should be recommended.
- Feeding practices recommended for moderately malnourished children less than 2 years of age should be consistent with recommendations formulated in the PAHO/WHO “Guiding principles for complementary feeding of the breastfed child” [5] and the WHO “Guiding principles for feeding non-breastfed children 6–24 months of age” [6].
- The effect of antinutrients in complementary foods based on the family diet can be decreased by various traditional food-processing methods, such as fermentation, malting, and soaking. The feasibility of using these processing techniques to improve nutrient bioavailability in the management of moderate malnutrition should be assessed.
- Since infections, food insecurity, and poverty are closely linked with malnutrition, dietary counseling for moderate malnutrition should be integrated with primary health care, such as IMCI, and with community development programs.
- Dietary counseling as a means to provide essential knowledge and skills will contribute to sustained improvements in feeding practices, which can potentially prevent malnutrition and/or relapse.
- Comprehensive program design is essential and should consider mechanisms for capacity-building, effective monitoring, and supportive supervision.

Research needs

Research questions in this area include whether to always aim to maximize the rate of catch-up in wasted children and what are the most appropriate delivery channels for dietary counseling. Research into the effectiveness of a combination of approaches for addressing moderate malnutrition is also needed, e.g., infection control and nutritional support and the combined and separate impact of food supplements and dietary counseling.

In order to inform this research agenda, researchers need to report weight gain as grams per kilogram per day (as well as the percentage moving between different weight-for-height and height-for-age categories), disaggregate weight gain among wasted and nonwasted children, and broaden the number of outcomes (e.g., body composition, height gain, immune function, morbidity). Overall, we need a better understanding of how to provide and deliver effective dietary counseling.

Food supplements used to treat moderate malnutrition in children (Paper 4)

This background paper (prepared by Dr. Saskia de Pee and Dr. Martin Bloem, World Food Programme [WFP]) reviewed specialized food supplements that are currently used to treat children with moderate malnutrition in different contexts. This includes fortified blended foods prepared with cereals and legumes as major ingredients, complementary food supplements providing nutrients and energy missing in the family diet, and micronutrient powders.

Dr. de Pee and Dr. Bloem reiterated that most supplementary feeding programs for moderately malnourished children supply fortified blended foods, such as corn–soy blend and wheat–soy blend, in combination with oil and sugar, but that there are a number of shortcomings with fortified blended foods used for this purpose, including too high a content of antinutrients, particularly phytate; absence of milk, which is important for growth; suboptimal micronutrient content, even though the food is fortified; and high bulk and viscosity, which limits intake by young children. For these reasons, fortified blended foods are not optimal for feeding moderately malnourished, as well as young, children and need to be improved and/or replaced by foods that better meet the nutritional needs of these children.

Presentations from WFP, UNICEF, and the US Agency for International Development (USAID) described the various improvements the agencies all plan to make to their fortified blended flour products, e.g., increasing the energy density, adding dairy products, dehulling soybeans, possibly removing cereal germ, changing the proportion of energy from fat, and improving the essential fatty acid and micronutrient profiles.

Improvements and adaptations to lipid-based nutrient supplements (LNS) and ready-to-use foods (RUFs) are also being made by the members of the LNS Research Network (supported by grants from the Bill and Melinda Gates Foundation and with support of the USAID-funded FANTA-2 Project) and Valid International.

Papers on field research from Malawi (Professor Ken Maleta, Blantyre College of Medicine), China (Professor Chen Chunming, International Life Science Institute), Niger and Sierra Leone (Dr. Susan Shepherd, Médecins sans Frontières–Nutrition Working Group), and Ghana (Professor Kathryn Dewey, University of California, Davis) presented data on the impact and outcomes of using specialized products to treat and prevent moderate malnutrition in different contexts. In Malawi, supplementary feeding of milk/peanut- and soy/peanut-fortified spreads to treat moderately wasted children resulted in slightly higher recovery rates than feeding with corn–soy blend. In Niger, a targeted Médecins sans Frontières supplementary feeding program for moderately wasted children using RUF had a 95% recovery rate. In Sierra Leone, the use of soy/peanut-fortified spread resulted in higher weight gain and shorter treatment than premix corn–soy blend/oil. In Ghana, children between 6 and 12 months of age who received a LNS had improved linear growth and were more likely to walk by 12 months of age as compared with control groups. In China, children receiving a soy-based micronutrient powder supplement from 4 to 24 months of age had improved linear and ponderal growth, reduced anemia prevalence, and improved IQ as compared with control group children. In Niger, the monthly incidence of low mid-upper-arm circumference (MUAC) decreased (compared with the incidence in the previous few years) after all children aged 6 to 36 months (blanket feeding) were given a LNS for 6 months during the hunger season.

After the discussion and the working group session that followed the presentations, the participants agreed on the following points:

» There is an urgent need to develop clear terminology for the different specialized foods used to treat moderate malnutrition. Classifications could be based on a number of variables: use of the product, e.g., ready-to-use bar or paste; purpose of the product, e.g., complementary food supplement; ingredients, e.g., LNS; and energy level, e.g., low, medium, or high.

» When it is expected that a new food product will have an impact on growth, morbidity, and micronutrient status at least equal to that of an existing product (often a fortified blended food such as corn–soy blend or wheat–soy blend), the participants suggested that it was then permissible to use this product in programs for feeding moderately malnourished children, provided that the product is acceptable to the beneficiaries. In that case, it is important to collect program data to monitor the impact of this new product on the time needed for recovery of children with moderate malnutrition if the product is used for treatment, or on the occurrence of new cases of malnutrition if it is used for prevention. Concurrently, the efficacy of the new product should also be assessed under carefully controlled circumstances in the same or another area or country, depending on local possibilities. Such efficacy testing should include measures of physiological, immunological, cognitive, and body compositional recovery as well as simple weight gain.

» Products that may be expected to have equal or better impact on growth, morbidity, and micronutrient status include those that have:
  — A nutrient density (in combination with the current diet of family food and breastmilk) consistent with current understanding of adequate nutrient intake for malnourished children;
  — Ingredients, fortificants, and hygiene criteria in accordance with Codex Alimentarius standards and guidelines suggesting that the product can be regarded as safe;
  — Production and packaging with appropriate quality control and quality assurance.

» It is very likely that different types of specialized foods and program formats (e.g., blanket or targeted dietary counseling) will be used to treat or prevent moderate malnutrition in the future, depending on the context (security, prevalence of malnutrition, general food security conditions, etc.). In some situations, blanket programs can also be regarded as treatment of a sick population, when there is evidence that nearly all children are underweight. The next WHO meeting on moderate malnutrition, which will focus on programming issues, should endeavor to develop algorithms for determining what program type and product to use in different situations.

Research needs

Areas of uncertainty still exist with respect to improving fortified blended foods. These include the impact of dehulling and degerming of soy, maize, and wheat; addition of phytase and/or amylase to improve nutrient availability and food acceptability; maximum tolerable fiber content; the minimal quantity of energy provided by fat to ensure adequate energy intake; the amount or proportion of milk required in the formula; and the possibility and efficacy of using plant protein isolates, especially soy protein isolates, as a possible substitute for dairy products. There is also a question regarding whether the antinutrient content of fortified blended foods can be significantly reduced by encouraging farmers to produce crop types that have naturally lower concentrations of antinutrients. More fundamentally, the question was raised whether it is still appropriate to invest in improving fortified blended food products when so many other new and potentially superior products are becoming available. The costs of fortified blended food compared with different alternatives and the use and purpose of the product, as well as the programming and opportunity costs of the different options, should be taken into account before answering this question.

Agencies urgently need to collect impact assessment data from the different products (fortified blended food, RUF, LNS, and micronutrient powders) being used to treat and prevent moderate malnutrition in different contexts so that field agencies and governments know which product to use in a given context. Often, these terms (fortified blended food, RUF, LNS, micronutrient powders) are used for products with significant variability in ingredients and manufacturing processes. For example, USAID, WFP, and UNICEF each have different specifications for fortified blended food, often under the same generic term of corn–soy blend, yielding products with different nutritional composition and fiber content. For this reason, it is suggested that leading organizations collaborate to develop standard specification(s) for these products or utilize different names for products produced under different specifications. Nongovernmental organizations (NGOs) or researchers collecting data on the effectiveness of fortified blended foods should indicate the source of the product (e.g., USAID, WFP, UNICEF) and the manufacturer (if available).

The impact and outcome data need to be comparable across studies and program evaluation. Information on nonfood context factors (e.g., program incentives) should also be collected. The operational advantages of some products or program types should be recorded (e.g., blanket distributions may be easier in food-insecure areas). Much of the work on the treatment of moderate malnutrition with new products has taken place in sub-Saharan Africa. There is a need to assess how applicable the research findings are to children with moderate malnutrition in Asia and other parts of the world.

It is essential to collect information on the costs of providing different types of specialized products, complementary interventions, and the means of distribution. Ultimately, if all children with moderate malnutrition are to be treated (i.e., not just those with moderate malnutrition due to emergencies), there is a need to consider what national governments and development agencies can afford.

Recommendations of the meeting: Next steps

In addition to endorsing the technical consensus statements and identified research needs mentioned in different sections of this report, the participants made recommendations to move forward and to continue to improve current programs in the next few years.

1. Establishment of a process to develop specifications for food categories for moderately malnourished children and validation of new products for prevention and treatment of moderate malnutrition in children

As an introduction to this discussion, a representative from FAO, Dr. Jeronimas Maskeliunas from the Codex Alimentarius secretariat, gave a presentation on the objectives of the Codex Alimentarius, its modus operandi, and its publications that are relevant to moderate malnutrition in children. The objectives include "to promote coordination of all food standards by international NGOs and Governments and to produce and amend standards, Codes of Practice, Guidelines and other documents."

Also, Dr. Carlos Navarro-Colorado, representing the Emergency Nutrition Network, presented a description of a generic approach to validate the efficacy of new foods for moderate malnutrition. This would need to be based upon clear classification of different types of food supplements required and the nutrient specifications for each category of food supplement. Four stages of validation were proposed: analysis of composition and processing, small-scale clinical pilot, field efficacy trial, and postvalidation monitoring. It will not be necessary to conduct all four stages for all products.

The design of studies and validation of products will face a number of challenges. These include lack of baseline dietary information, accounting for differences in the quality of program implementation, the need to broaden and define outcome indicators beyond anthropometry, and accounting for the fact that an unknown proportion of moderately malnourished children will recover spontaneously. Another significant challenge will be how to establish an institutional mechanism and identify a lead agency for ensuring coordinated validation of products.

A working group then examined how to move forward and how to set up a process of improving existing food supplements and ensure their efficacy is adequately evaluated. The group made the following statements, which were reviewed and approved in the final plenary session:

» Moderate malnutrition is a pathological process that requires special dietary treatment. There is a need to develop specific recommendations for adequate dietary intakes of energy and all nutrients for different categories of children with moderate malnutrition (stunted and wasted).

- A standing task force should be established and led by WHO with appropriate UN agencies and other technical experts to develop specifications for specialized products, in particular for moderately wasted children in a first step. In view of the uncertainties about the nature of diets needed by stunted children, this task force should provide guidance for testing new products. This task force should work in collaboration with the Codex Alimentarius working group.
- A separate expert group should be established, also in collaboration with the Codex Alimentarius, to examine different endogenous food components that have potential negative effects and develop upper limits for these antinutrients and toxins. One of the tasks of this group would be to determine the maximum acceptable level of different types of dietary fibers and other potentially deleterious natural constituents that can be present in food supplements.
- There is a need for an independent standing working group to assist national governments and agencies to determine if newly available products that are put onto the market are appropriate and whether (a) particular type(s) of product testing are required before granting approval for their use among specific target groups.
- The meeting recommended that this set of activities should be initiated within the next 6 months.

Research needs

In the discussions, the meeting also identified the need to estimate the level at which recovery from moderate malnutrition occurs in the absence of supplementation, so that this can be accounted for in trials involving new products. This can be achieved either by examining data from previous studies in which some children did not receive any supplement or by taking as a control group in intervention studies a group receiving adequate dietary counseling but no food supplement. The latter option, however, will be acceptable only in a context of good food security, where families have access to nutrient-dense foods.

There is also a need to elaborate specific non-anthropometric measures that can be used to compare outcomes and product efficacy. This will involve developing and strengthening field-friendly techniques for measuring outcomes, such as body composition immunocompetence, micronutrient status, renal concentrating ability, physical activity level, sodium pump function, intellectual development, etc.

2. Organization of a second meeting on improving programs addressing the management of moderate malnutrition

The focus of this technical meeting was dietary requirements of children with moderate malnutrition, so that programmatic issues were not substantively addressed. WHO is planning a further technical meeting on programming for children with moderate malnutrition. The participants supported this initiative, and during the penultimate session a plenary debate regarding a possible agenda for this second meeting was organized. Although there was broad consensus regarding key subject areas for the agenda, there was some debate over whether the meeting should focus on wasting and prevention of stunting and omit treatment of stunting due to current knowledge and resources gaps. This issue will be resolved in the coming months. There was also unresolved debate over the extent to which HIV/AIDS should form part of the meeting agenda.

Agenda issues where there was broad agreement were clarification of program selection and exit criteria for children with moderate malnutrition and relevant indicators; developing a program typology, taking into account the program context, describing the situation where targeted and blanket food distribution should be implemented, and learning from experiences gained in the community management of severe acute malnutrition, especially with regard to integration of programs into government systems; and identifying target age groups for treatment. There is a need also to assess costs and effectiveness of different programming modalities and broadening modalities for addressing moderate malnutrition to include cash or voucher-type interventions. The meeting should also tackle issues related to monitoring and evaluation, as well as review emerging knowledge regarding barriers to access and utilization of programs, default from programs, and nonresponse to supplementation.

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