

IMPROVING CHILD GROWTH

During the first two or three years after birth, children in developing countries grow more slowly than those in wealthier regions of the world. It is difficult for them to regain this lost growth potential in later years, especially if they remain in the same environment. In the previous section, it was shown that undernutrition of the mother at conception and during pregnancy has a strongly adverse influence on early growth of her foetus, which is then a risk factor for subsequent growth stunting of the infant and young child. However, there is no doubt that feeding practices during the first years of life also have an important influence on the nutritional status, growth and function of the young child.

This section starts by describing the growth patterns of infants and children in developing countries, the regional prevalence rates of stunting, underweight, and wasting and the causes and consequences of these outcomes. This is followed by consideration of recommended child feeding practices in the first years of life and the type of problems encountered during the period of complementary feeding. The latest evidence on the efficacy of approaches aimed at improving complementary feeding is reviewed, followed by the impact of micronutrient supplementation interventions on growth. While the focus here is on infants and preschool children, because of their greater vulnerability to undernutrition and the special problems of feeding young children, many of the general principles described below apply equally well to older children.

Growth Patterns of Infants and Children

It is universally accepted that anthropometry is the most useful tool for assessing the nutrition status, and risks of poor health and survival of infants and young children. The current international reference data¹²⁷ are far from perfect. They were obtained by measuring infants between 1929 and 1975 in the USA. These reference infants were predominantly formula-

fed, and from non-representative genetic, geographical and socioeconomic backgrounds. Well nourished breastfed infants generally grow more rapidly than formula-fed infants (and thus more rapidly than the growth reference) during the first 2 to 3 months of life. However, they then grow more slowly than the growth reference between 3 and 12 months. These expected differences in growth, related to the type of early feeding, should be considered when comparing the growth of exclusively breastfed infants to the growth reference. After 12 months of age, the disparity in growth between well nourished breastfed infants and the growth reference is no longer seen. The National Center for Health Statistics (NCHS) published revised growth charts in May, 2000, based on more recent surveys in the USA¹⁶⁷. However, these surveys included few infants who were breastfed for more than a few months. The new reference values for weight-for-age (but not height-for-age) towards the end of the first year of life are substantially higher than those for infants who were exclusively breastfed for 4 months then partially breastfed thereafter¹⁶⁸. The growth references will be revised, after the completion of a multicentre, international, infant growth study that is being coordinated and supervised by the WHO¹⁶⁹.

Three anthropometric indices are commonly used to assess infants and children: length-for-age (LA) or height-for-age (HA), weight-for-age (WA), and weight-for-length (WL) or weight-for-height (WH). Length is usually measured before a child is two years old, and height thereafter. Reported changes in growth rates or size at around 2 years are sometimes an artefact of the discontinuity of the growth curves at this age.

Growth data are usually expressed as Z-scores, calculated as the deviation of the value for an individual from the reference population at that age, divided by the standard deviation for the reference population. Z-scores correct for differences in age among a group of children. Low LA or HA (stunting) is usually an indication of long term undernutrition. Low WA is a less useful measure because it can be caused by stunting, accompanied by low, normal, or larger than normal amounts of fat and muscle. Low

WL or WH (wasting) may be the result of recent undernutrition that has caused tissue loss but has not yet affected stature.

Stunting

The WHO has established ranges that can be used to classify populations on the basis of the prevalence of stunting. Stunting is defined as more than 2 standard deviations below the median value of the NCHS/WHO International Growth Reference for length- or height-for-age¹²⁷. For children less than 5 years old, a low prevalence of stunting is <20%, whereas 20-29% indicates a medium prevalence, 30-39% a high prevalence, and $\geq 40\%$ a very high prevalence. Stunting usually becomes more prevalent after 3 months of age. The rate of decline in Z-scores starts to slow down at around 18 months and is very gradual after 24 months. Height Z-scores usually stop declining after around 3 years of age.

The global prevalence of stunting in children under 5 years averages about 33% in developing countries, but varies widely among them¹¹. South Central Asia has the second highest prevalence of stunting in the world (44%), exceeded only by East Africa (48%). West Africa (35%), South-East Asia (33%), Central America (24%), North Africa (20%), the Caribbean (19%) and South America (13%) follow in order of prevalence. Data are not good enough to permit estimates to be made for East and West Asia¹¹. Asia is home to about 128 million (70%) of the world's 182 million stunted children aged under 5 years. The prevalence in South Central and South-East Asia was about 5% lower in 2000 than it was in 1995. This is encouraging, but at the present rate it will take many decades to reduce the prevalence of stunting in Asia to acceptable levels. Nine countries in Asia (shaded in Table 3) have a very high prevalence of stunting. An analysis of global data revealed that higher per capita energy availability, female literacy, and gross national product (GNP) were the most important factors explaining national differences in stunting¹⁷⁰.

Because stunting is a cumulative process, the percent of stunted children increases with age. Such increases in stunting prevalence with age do not necessarily indicate that the nutrient intake and status of the children are worse at two years of life than earlier, although they often are. Rather, it reflects the cumulative nature of stunting.

Underweight

The global prevalence of low WA, defined as more than 2 standard deviations below the NCHS/WHO international growth reference WA median, is

substantially lower than that of stunting. In other words, undernutrition in early life is more typically manifested as stunting than as low weight. Underweight is a function of short stature, low tissue mass, or both. Although it is more difficult to interpret, WA is often used to screen for undernutrition because it does not require measurements of height. It is important to recognize that WA data underestimate substantially the number of malnourished children.

The WHO classifications of the prevalence of underweight are: <10%, low prevalence; 10-19%, medium; 20-29%, high; and $\geq 30\%$, very high. The global prevalence is 26.7%. South Central Asia has the highest prevalence in the world (43.6%). In South-East Asia it is 28.9% and in Asia overall, 29.0%¹¹. The national patterns and differences in underweight adequacy are similar to those for stunting (Table 3). Most (72%) of the underweight children in the world live in Asia, especially in South Central Asia. The fall in prevalence of underweight in Asia from 1995 to 2000 was 3-4%, about the same as the decline on a global basis. As with stunting, the prevalence of low WA also increases with age.

Wasting

Wasting is defined as more than 2 standard deviations below the NCHS/WHO international growth reference weight-for-height median. It is usually caused by a relatively recent illness or food shortage that induces acute and severe weight loss, although chronic undernutrition or illness can also cause this condition. The prevalence of wasting is much lower than that of stunting or underweight. The expected prevalence in developing countries is 2-3%. When wasting rises to about 5%, mortality rates increase substantially¹²⁷. In Asia, the overall prevalence is 10.4%, and is highest in South Central Asia (15.4%), 10.4% in South-East Asia, and lower in East Asia (3.4%). Data are not yet available for West Asia. The global prevalence is 9.4% for developing countries. The prevalences in South Central Asia (15.4%) and West Africa (15.6%) are the highest in the world.

Causes of Poor Growth

The most common immediate causes of poor growth of humans in developing countries include: poor maternal nutrition status at conception and undernutrition *in utero*; inadequate breastfeeding; delayed complementary feeding, inadequate quality or quantity of complementary feeding; impaired absorption of nutrients due to intestinal infections or parasites; or combinations of these problems (Figure 3).

TABLE 3: Prevalence (%) of stunting and underweight in preschool children and corresponding gross national product (GNP) per capita in the Asia-Pacific region ^a

Country	Year(s) of survey	1998 GNP per capita (US \$)	Stunting ^b %	Underweight ^c %
Afghanistan	1997	< 760	47.6	-
Bangladesh	1996-97	350	54.6	56.3
Bhutan	1986-88	< 760	56.1	37.9
Cambodia ^d	1996	N/A	56.0	52.0
People's Republic of China	1992	750	31.4	17.4
Fiji Islands	1993	2110	2.7	7.9
India	1992-93	430	51.8	53.4
Indonesia	1995	680	42.2	34.0
Kazakhstan	1995	1310	15.8	8.3
Kiribati	1985	1180	28.3	12.9
Kyrgyzstan	1997	350	24.8	11.0
Lao PDR	1994	330	47.3	40.0
Malaysia	1995	3600	-	20.1
Maldives	1995	1230	26.9	43.2
Myanmar	1994	< 760	44.6	42.9
Nepal	1996	210	48.4	46.9
Pakistan	1990-91	480	49.6	38.2
Papua New Guinea	1982-83	890	43.2	29.9
Philippines	1993	1050	32.7	29.6
Solomon Islands	1989	750	27.3	21.3
Sri Lanka	1993	810	23.8	37.7
Thailand	1987	2200	21.5	25.3
Tonga	1986	1690	1.3	-
Uzbekistan	1996	870	31.3	18.8
Vanuatu	1983	1270	19.1	19.7
Viet Nam	1994	330	46.9	44.9

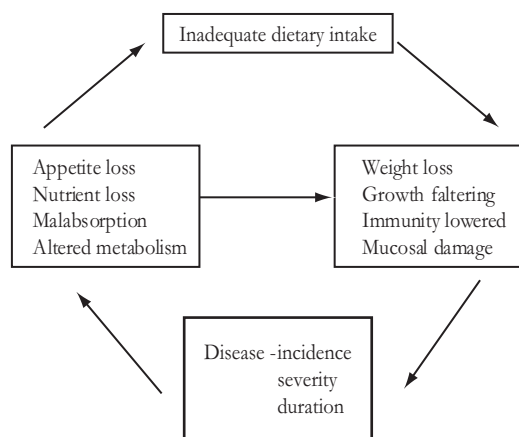
Source: WHO (1999) Global Database on Child Growth and Malnutrition. Forecast of Trends. Geneva: Nutrition Division, WHO.

Notes: ^a Shaded cells (stunting) show the countries with the highest rates of stunting (>40%) for which 1990s data are available. Shaded cells (GNP) show the poorest countries (GNP per capita <US\$760). There is clearly a strong association.

^b Stunting - The anthropometric index 'height-for-age' reflects linear growth achieved pre- and postnatally, with deficits indicating longterm, cumulative effects of inadequacies of nutrition and/or health. Shortness in height refers to a child who exhibits low height-for-age that may reflect either normal variation in growth or a deficit in growth. Stunting refers only to shortness that is a deficit, or linear growth that has failed to reach genetic potential as a result, most proximally, of the interaction between poor diet and disease. Stunting is defined as low height-for-age; i.e., below 2 standard deviations (or 2 Z-scores) of the median value of the National Center for Health Statistics/World Health Organization International Growth Reference for length- or height-for-age.

^c Underweight - The anthropometric index 'weight-for-age' represents body mass relative to age. Weight-for-age is influenced by the height of the child and his or her weight and is thus a composite of stunting and wasting (which makes its interpretation difficult). In the absence of wasting, both weight-for-age and height-for-age reflect the long term nutrition and health experience of the individual or population. General lightness in weight refers to a child having a low weight-for-age. Lightness may represent either normal variation or a deficit. Underweight specifically refers to lightness that is a deficit and is defined as low weight-for-age, i.e.; below 2 standard deviations (or 2 Z-scores) of the median value of the National Center for Health Statistics/World Health Organization International Growth Reference for weight-for-age.

^d Cambodian national data are from the 1996 UNICEF Multiple Indicator Cluster Survey for 6 to 59 month-old children.

FIGURE 3: The inadequate dietary intake – disease cycle

Source: Tomkins A, Watson F (1989) *Malnutrition and Infection*. ACC/SCN State-of-the-Art Series Nutrition Policy Discussion Paper No. 5. Geneva: ACC/SCN.

Interactions Between Undernutrition and Diseases

Undernutrition is almost always the result of combinations of diseases and dietary inadequacies interacting in a mutually reinforcing manner (Figure 1). Undernutrition lowers immuno-competence and increases the risk and severity of infection. Inadequate dietary intake may cause death without the influence of any disease, and disease (e.g., measles or malaria) may cause death even in well nourished children. However, the most common cause of death is the combination of inadequate dietary intake and disease. Disease may affect dietary intake (i.e., through anorexia) and inadequate dietary intake may cause disease through contamination.

These interactions between inadequate dietary intake and disease, in the form of a vicious cycle, have been referred to as the “malnutrition-infection complex”. Strictly speaking, however, it is a complex between the two immediate causes, with undernutrition being the outcome. This complex remains the most prevalent public health problem in the world today.

The interactions of nutrition and infection with regard to individual infections and defined nutrients are now better known. For example, protein-energy malnutrition increases the duration of episodes of diarrhoea. The importance of interactions between VAD and a number of infectious diseases (notably measles) are now becoming clear. VAD also affects epithelial membranes, and thus relates to respiratory tract infections and to diarrhoea. Deficiencies of other

micronutrients, even when clinical signs are not present, exert an influence through such routes as lowered immunocompetence (e.g., iron deficiency) and integrity of epithelial tissues. Zinc may also have a general effect on infectious disease, again at least partly through the immune system.

Inadequate dietary intake can cause weight loss or growth failure in children and leads to low nutrition reserves. Almost all nutrient deficiencies are probably associated with a lowering of immunity. There may be progressive damage to the mucosa, lowering resistance to colonization and invasion by pathogens, particularly in protein-energy and vitamin A deficiencies. Lowered immunity and mucosal damage are the major mechanisms by which defenses are compromised. Under these circumstances, diseases will have potentially increased incidence, severity, and duration.

The disease process itself exacerbates loss of nutrients, both by the host’s metabolic response, and by physical loss from the intestine. These factors exacerbate undernutrition, leading to further possible damage to defense mechanisms. At the same time, many diseases are associated with a loss of appetite and other possible disabilities, further lowering the dietary intake. Although other relationships play a part, this cycle summarises many of the most important relationships. It accounts for much of the high morbidity and mortality, under the circumstances of high exposure to infectious diseases and inadequate diet, that characterize many poor communities. The complex nature of the interaction has meant that it is very difficult to unravel and to distinguish cause from effect. Indeed, the understanding of which specific nutrient deficiencies contribute most to the high prevalence of stunting and wasting in developing countries is still relatively poor. This as well as the influence of non-nutrition factors explains, in part, why it has been so difficult to design effective intervention strategies.

Consequences of Poor Growth

Poor growth is strongly associated with risk of mortality. From a review of 28 community-based studies in 12 Asian and Sub-Saharan African countries, it was estimated that about 45 to 65% of child deaths are due to severe (<60% of median WA) plus moderate (60-69% of median WA) and mild (70-79% of median WA) undernutrition¹⁷¹. A WHO analysis of six longitudinal studies revealed a strong association between severity of WA deficits and mortality rates: 54% of deaths of children under 5 years in developing countries were accompanied by low WA¹²⁷.

Undernutrition's impact on illness, disability and death probably is substantial, and probably underestimated. The World Bank¹⁷² attributed between 20 to 25% of the global burden of disease in children to undernutrition, and 15.9% of total global (DALYs) to "malnutrition". The latter figure represents 18% of total developing world DALYs, 22.4 % of Indian DALYs, 5.3% of DALYs in the PRC and 14.5 percent of other Asian countries and islands DALYs¹⁷³. The definition used for "malnutrition" in such estimates was narrow. For example, the direct impacts of micronutrient deficiencies other than iron, vitamin A and iodine are not included, neither are the direct health consequences of overnutrition. Moreover, the estimates of the indirect impacts of undernutrition as a contributing risk factor for illness and death were partial and conservative: restricted to children, and to protein-energy malnutrition and vitamin A deficiency. If these other factors were to be included, they would not be perfectly additive, but would probably add substantially to overall contribution of malnutrition to global DALYs of 15.9%. Some commentators have made informal estimates that suggest the complete contribution of all forms of malnutrition could be as high as 50% of the global burden of disease¹⁷⁴.

When children reach the age of 3 years, their nutrient requirements fall, they become less vulnerable to stunting, and their diet usually improves. As a consequence, the growth rate of stunted children then becomes fairly normal. They remain short, but do not continue to become shorter relative to the growth reference. Although there may be some growth catch-up of stunted children in adolescence, related to their delayed maturation and more time for growth, this does not usually compensate for failure to grow in early childhood²⁸ (see above). Stunted children have caught-up growth substantially when adopted into environments in which they have become well-fed and healthy, or have recovered from a chronic illness¹⁵⁹. The short stature of adults in developing countries is largely the result of poor growth during the first three years of life. In Guatemala, supplementation in early childhood improved the stature, fat-free mass and work capacity of adolescents and young adults^{175, 176}. Specifically, adolescent males who had been supplemented with a high protein-energy supplement during early life were 0.8 cm taller, 1.3 kg heavier, had a 1.2 kg greater fat-free mass and a 0.38 L/min higher maximum oxygen consumption than those who had been given a low energy, no protein supplement. Similar results were found for females.

Undernutrition in early childhood is often associated with poor cognitive and motor development. In a meta-analysis, LBW (whether

caused by IUGR or prematurity) predicted a 6-point reduction in IQ during school age¹⁷⁷. Most of the data were from developed countries. The impact is probably stronger in poor environments. Children who have been severely undernourished in early childhood suffer a later reduction in IQ of as much as 15 points¹⁷⁸. In Guatemala, supplementation in early childhood improved reading and vocabulary scores in adolescence and young adulthood, but did not affect performance on the Ravens Progressive Matrices test^{179, 180}. Psychosocial stimulation, in addition to supplementation, can improve the development quotient of young children, with the maximal effect obtained by a combination of both¹⁸¹ (Figure 4). Improved early nutrition and care can compensate in part for undernutrition *in utero*.

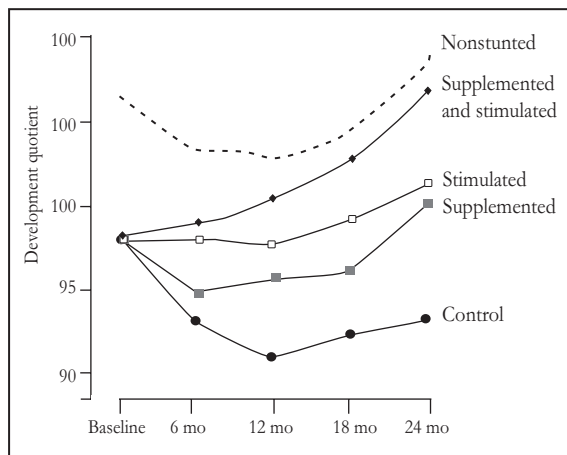
In addition to the adverse effects of early undernutrition (*in utero* and in early infancy) on brain development, there is a complex interaction between the apathy and relative inactivity of undernourished young children and their stimulation by their environment¹⁸². In a longitudinal study in Cebu, Philippines, children who were stunted between birth and 2 years had significantly lower cognitive ability when tested at age 8 to 11 years¹⁵². The earlier that children became stunted, the more the severe their stunting, and the greater their impairment in later cognitive ability. Much of the shortfall in test scores was caused by the stunted children's later age of enrollment in school, poorer attendance and greater repetition of school grades. Stunted children may be treated differently because they are smaller and appear to be younger, and they may appear to their parents to be less alert and less ready for schooling¹⁸². Schooling acts as a buffer against the effects of poverty and malnutrition on intellectual function¹⁸³.

The Fundamental Importance of Care

Care, as it came to be defined during the 1990s, refers to the behaviour and practices of caregivers (mothers, siblings, fathers, and child care providers) who provide the food, health care, psychosocial stimulation and emotional support necessary for the healthy growth and development of children^{4, 184}. These practices and the ways in which they are performed (with affection and with responsiveness to children) are critical to survival, growth, and development of children. They translate food security and health care into a child's well being (Figure 2). It is impossible for caregivers to provide this care without sufficient resources, such as time, energy and money.

A Care Initiative Manual, developed by the United Nations Children's Emergency Fund (UNICEF)¹⁸⁵, lists

FIGURE 4: Development quotients of stunted children with various treatments, compared to those for nonstunted children and controls



Source: Grantham-McGregor SM, Powell CA, Walker SP, Himes JH (1991) Nutritional supplementation, psychosocial stimulation and mental development of stunted children: the Jamaican study. *The Lancet* 388: 1-5.

six care practices, with subcategories, and three kinds of resources needed for good child care. For example, mothers are often advised to increase the frequency of feeding, but they may have too much work to have the time for giving an additional feed, and may find themselves blamed for providing inadequate care.

Care practices and resources for care are important not only for the good nutrition status of children, but also for their growth and development. They have been recognized as the building blocks of UNICEF's integrated approach to young children, called "Early Childhood Care for Survival, Growth and Development"¹⁸⁶. The six care practices are described briefly here, before a detailed discussion of care practices in breastfeeding and complementary feeding.

First, care for women requires behaviour in the family to support women, including making sure that they receive adequate prenatal care and safe delivery, and have equal access to education. Second, food preparation takes enormous amounts of the time and effort of caregivers. Adequate stoves lessen the exposure of women to indoor air pollution. Third, hygiene practices have long been recognized as critical for child nutrition. Fourth, home health practices are important, including the diagnosis of illness in the home, preventative health care, protection from pests, and prevention of accidents. Fifth, good psychosocial care is needed, including warmth, verbal interaction and encouragement of learning, which improved cognitive

development of children (Figure 4), and is related to complementary feeding styles. Feeding, including breastfeeding and complementary feeding, is the sixth care practice. This is discussed in the following section, and the large scale effectiveness of care interventions is discussed in the penultimate section.

The significance of care practices for the nutrition status of children was investigated for 475 low-income households in Accra, Ghana, that had a child between 4 and 36 months of age¹⁸⁷. Based on a recall questionnaire, a 'care practices' scale was constructed. The scale reflected breastfeeding patterns, timing of complementary feeding, food quality, and two questions related to feeding practices: whether anyone helps the child to eat? (28 % said no); and whether the caregiver "does anything" if the child refuses food? (21 % do nothing). There was a significant association between scores on the care practices scale and stunting and underweight of the children. Interestingly, care practices were unrelated to children's height-for-age if their mothers had secondary education, but care practices were highly related to children's nutrition status if mothers had only primary or less education. The effect of income was insignificant, when controlling for maternal schooling and care practices. This would suggest that less educated mothers should be targeted for special messages about care.

Exclusive Breastfeeding

Frequent, exclusive breastfeeding is important in the early weeks of lactation in order to stimulate optimal milk production. "On-demand" feeding leads to earlier maximal milk production than feeding on a fixed schedule. The introduction of any other foods or fluids, including water, is likely to reduce the infant's demand for breastmilk, and to interfere with the maintenance of lactation, ending with early termination of breastfeeding. No fluids other than breastmilk are required by the young infant. When infants are given solid foods, or even nonmilk fluids, the prevalence of diarrhoea is much higher due to contamination of the bottles or food^{188, 189}. During diarrhoea and fever, breastfed infants will continue to consume breastmilk but will reduce their intake of complementary foods and fluids¹⁹⁰. From a nutrition perspective, it is important to recognize that any other foods will displace at least some breastmilk, especially in the first six months of life¹⁹¹. Because breastmilk is generally higher in most nutrients than other foods available to young infants, nutrient intake will be lower when other foods are introduced too early. Many other biological, nutrition and psychological advantages to breastfeeding have been described in detail elsewhere^{192, 193}.

Exclusive breastfeeding is recommended for the first 6 months of life¹⁹⁴. Reviewers of evidence as to whether 4 or 6 months is the best age to introduce complementary foods, concluded that there was no advantage to starting before six months¹⁹¹. In Honduras, there was no improvement in growth when SGA, breastfed infants were given hygienically prepared, nutritious, complementary foods at 4 months compared to 6 months¹⁹⁵. Although growth and morbidity were not higher when complementary foods were introduced at 4 vs. 6 months, this may be explained by the fact that the foods used in this study were hygienically prepared and stored. However, there are still few data from controlled studies that compare the merits of starting supplementation at 4 or 6 months.

Complementary Feeding

Complementary feeding is defined as the period during which foods or liquids are provided along with continued breastfeeding. Complementary food is the term used to describe any nutrient-containing foods or liquids, other than breastmilk, that are given to young children during the period of complementary feeding¹⁹¹. Complementary food includes special “transitional” foods that are prepared especially for the infant and, increasingly as the child becomes older, the same foods that are consumed by other members of the household.

Recommendations for Complementary Feeding

A recent review of current recommendations for complementary feeding revealed some similarities, as well as many differences, among national and international organizations¹⁶⁸. The similarities include: the need for a gradual transition from soft foods to family foods; starting complementary feeding some time between 4 and 6 months of age; and introducing cereals first and avoiding offering cow’s milk until 9-12 months of age. The differences include: mention or lack of mention of the need for iron-fortified foods, specific vitamin A sources, meat, poultry, fish, and vitamin - mineral supplements; and the recommended number of meals. The need to reinforce the importance of continued breastfeeding is often overlooked. There is a critical need for international guidelines that provide advice about best feeding practices (including breastfeeding) during the first years of life. WHO has recently published such guidelines for the WHO European Region¹⁹⁶.

As a general rule, the nutrient intake of the young child deteriorates when complementary foods start to substitute for breastmilk. Complementary feeding is

poorly done in many developing countries, due to lack of information about what foods are appropriate, how much should be given, how they should be given, and their inadequacy in quantity and quality, among other problems. WHO commissioned a major review of these questions¹⁹¹. A brief summary of the relevant conclusions follows here.

Estimating the Amount of Nutrients Needed in Complementary Foods

The WHO report¹⁹¹ provides estimates of the amount of nutrients that should be consumed in complementary foods. The approach used was to estimate the usual intake of each nutrient from breastmilk, for infants consuming low, average and high amounts of breastmilk between 6 and 24 months of age. The usual intakes were calculated as the average reported volumes of breastmilk consumed in developing (and separately in developed) countries, and average values for the nutrient content of human milk. The nutrient intakes estimated in this way were then subtracted from the recommended intakes for each nutrient, producing an estimate of the amount of each nutrient that is needed from complementary foods. If desired, these values, (Table 4) can be modified by substituting country-specific, recommended nutrient intakes or breastmilk composition data. It should be emphasized that the following calculations were based on estimates of the nutrient content of breastmilk of women in developed countries (except for vitamin A) due to lack of adequate information from developing countries. This means that the contribution of breastmilk to the infant’s intake of some nutrients has been overestimated, and the need for these nutrients from complementary foods has been underestimated, where maternal undernutrition has reduced the breastmilk content of these nutrients.

The nutrient requirements (with variations depending on age) from complementary foods, for infants that consume average intakes of breastmilk after the age of 6 months, are as follows: energy, 50-70%; protein, 20-45%; vitamin A, 5-30%; thiamine, 50-80%; riboflavin, 50-65%; calcium, 60%; vitamin B₆, 75-88%; zinc, 85%; and almost 100% for iron. Importantly, almost no vitamin B₁₂, C, or folate is needed from complementary foods if some breastmilk is consumed, because breastmilk is so high in these vitamins. An important caveat here is that maternal undernutrition can easily reduce the content of vitamin B₁₂ in breastmilk. Breastmilk also makes a very important contribution to meeting the vitamin A requirements of the infant, although maternal vitamin A depletion will also lower the content of this vitamin in breastmilk.

TABLE 4: Estimated daily amounts of nutrients needed from complementary foods, by age of infants, and usual breastmilk intake in developing countries

Nutrient	6-8 months Breastmilk intake (mL)			9-11 months Breastmilk intake (mL)			12-23 months Breastmilk intake (mL)		
	Low 350	Avg. 666	High 982	Low 253	Avg. 611	High 969	Low 145	Avg. 558	High 971
Energy (kcal)	465	269	73	673	451	229	1002	746	490
Protein (g)	5	2	0	7	3	0	9	5	1
Vitamin A (µgRE)	164	13	0	214	42	0	313	126	0
Folate (µg)	0	0	0	9	0	0	35	3	0
Niacin (mg)	3	3	3	5	4	4	8	7	7
Riboflavin (mg)	0.3	0.2	0.1	0.3	0.2	0.1	0.5	0.4	0.3
Thiamine (mg)	0.1	0.1	0	0.2	0.2	0.1	0.5	0.4	0.3
Vitamin B ₆ (mg)	0.26	0.21	0.17	0.27	0.22	0.17	0.28	0.23	0.17
Vitamin B ₁₂ (µg)	0	0	0	0.1	0	0	0.3	0	0
Vitamin C (mg)	10	0	0	14	0	0	23	8	0
Vitamin D (µg)	6.8	6.6	6.5	6.9	6.7	6.5	7	6.7	6.4
Vitamin K (µg)	9.2	9	8	9.4	9	8	9.6	9	8
Calcium (mg)	421	336	252	449	353	256	301	196	92
Copper (mg)	0.2	0.1	0.1	0.2	0.1	0.1	0.4	0.3	0.2
Iodine (µg)	19	0	0	30	0	0	51	10	0
Iron (mg):									
low bioavailability	21	21	21	21	21	21	12	12	12
medium bioavailability	11	11	11	11	11	11	6	6	6
high bioavailability	7	7	7	7	7	7	4	4	4
Magnesium (mg)	62	51	41	70	58	46	79	66	53
Phosphorus (mg)	348	306	263	362	314	266	246	193	141
Selenium (µg)	3	0	0	5	0	0	11	4	0
Zinc (mg)	2.5	2.2	1.9	2.6	2.3	2.1	2.7	2.4	2.1

Source: Adapted from Brown KH, Dewey KG, Allen LH (1998) *Complementary feeding of young children in developing countries: a review of current scientific knowledge*. Geneva: WHO.

Nutrient density (Table 5) refers to the amount of a given nutrient per 100 kcal of food, and is calculated from the ratio of the amount of each nutrient needed from complementary foods to the amount of energy needed from complementary foods. Nutrient density

is an important consideration because it is not high enough in many of the foods available for complementary feeding. This means that the intake of nutrients from such foods will be inadequate, even when the infant's energy needs are met.

TABLE 5: Desirable nutrient density of complementary foods (per 100 kcal) by age of infants, and usual breastmilk intake in developing countries

Nutrient	6-8 months Breastmilk intake (mL)			9-11 months Breastmilk intake (mL)			12-23 months Breastmilk intake (mL)		
	Low 350	Avg. 666	High 982	Low 253	Avg. 611	High 960	Low 145	Avg. 558	High 971
Protein (g)	1.1	0.7	0	1	0.7	0	0.9	0.7	0.2
Vitamin A (µgRE)	35	5	0	32	9	0	31	17	0
Folate (µg)	0	0	0	1	0	0	3	0	0
Niacin (mg)	0.6	1.1	4.1	0.7	0.9	1.7	0.8	0.9	1.4
Riboflavin (mg)	0.3	0.2	0.1	0.3	0.2	0.1	0.5	0.4	0.3
Thiamine (mg)	0.1	0.1	0	0.2	0.2	0.1	0.5	0.4	0.3
Vitamin B ₆ (mg)	0.05	0.08	0.23	0.04	0.05	0.08	0.03	0.03	0.04
Vitamin B ₁₂ (µg)	0	0	0	0.01	0	0	0.03	0	0
Vitamin C (mg)	2.2	0	0	2.1	0	0	2.3	0	0
Vitamin D (µg)	1.5	2.5	8.9	1	1.5	2.8	0.7	0.9	1.3
Vitamin K (µg)	2	3.3	11	1.4	2	3.5	1	1.2	1.6
Calcium (mg)	91	125	345	67	78	112	30	26	19
Copper (mg)	0.04	0.04	0.14	0.03	0.02	0.04	0.04	0.04	0.04
Iodine (µg)	4	0	0	4	0	0	5	1	0
Iron (mg):									
low bioavailability	4	8	28	31	5	9	1	2	2
medium bioavailability	2	4	15	2	2	5	1	1	1
high bioavailability	1	2	9	1	1	3	0	1	1
Magnesium (mg)	13	19	56	10	13	20	8	9	11
Phosphorus (mg)	75	114	360	54	70	116	25	26	29
Selenium (µg)	0.6	0	0	0.7	0	0	1.1	0.5	0
Zinc (mg)	0.5	0.8	2.6	0.4	0.5	0.9	0.3	0.3	0.4

Source: Adapted from Brown KH, Dewey KG, Allen LH (1998) *Complementary feeding of young children in developing countries: a review of current scientific knowledge*. Geneva: WHO.

Improving the Nutrient Content of Complementary Foods

Increasing Energy Intake

It is difficult to interpret associations between energy intake and growth. When energy intake from foods is low, the intake of many other nutrients will also be inadequate. Experiments in which the energy content of infant formulae was varied, while keeping the protein content constant, indicate that energy deficiency affects growth in weight but not in height, at least in the short term^{197, 198}. Intervention studies, supplying energy alone as additional fat or a high energy food, have not found a consistent effect on growth. In Papua New Guinea, energy supplements increased the weight gain and fatness of school children, but not their linear growth^{199, 200}. In contrast,

a high energy food (310 kcal/day) given to undernourished Indian children increased both their height and weight gain²⁰¹.

Many complementary foods have a low energy density. The recommended energy density of complementary foods fed three times a day to infants consuming average amounts of breastmilk, is 0.6 kcal/g at 6-8 months, increasing to 1.0 kcal/g at 12-23 months. If the intake of breastmilk is low, the energy density may need to be 0.8-1.2 kcal/g. In contrast to these recommendations, the energy density of many gruels, soups, and broths fed to children in developing countries is below 0.3 kcal/g. The number of daily feedings of these watery foods may already be high, in which case it would be best to increase their energy density, rather than the number of feeds per day¹⁹¹.

Energy density can be increased by reducing the viscosity of cereals with amylases. These can be

purchased commercially or made by germinating local cereals. This strategy has achieved mixed results. Although an amylase-treated, cereal porridge can be fed more rapidly and needs less added water, such foods are slightly more expensive and take longer to prepare. They also carry a higher risk of bacterial contamination if home-produced amylases are used. Amylase treatment increased energy intake in only five out of eight studies¹⁹¹. Concerns about the microbiological safety of foods treated with amylase, and the lack of clear efficacy of increasing energy intake, suggest that extensive promotion of amylase treatment approach is not justified at this time.

Another approach, often recommended to increase energy density is to add fats or sugars to complementary foods. However, adding oils or sugars to foods aggravates the problem of already low nutrient density. For example, it has been calculated that adding one teaspoon of oil to 100 g of maize gruel in West Africa would reduce protein density from 8.9 to 3.3% of energy, and iron density from 0.5 to 0.2 mg/kcal¹⁹¹.

Increasing Protein Intake

In most situations, the protein intakes of infants are adequate²⁰², especially if they are consuming some breastmilk^{191, 203}. Trials with infant formulas revealed that changing energy intake, while holding protein intake constant and adequate, affected the weight (fatness) of infants rather than their linear growth¹⁹⁷. In the INCAP longitudinal study in Guatemala²⁰⁴, there was no added benefit from providing infants and preschool children with good quality protein compared to energy alone. Protein was given here as *atole*, a gruel prepared from dried skim milk and cereal. Energy intake was the strongest predictor of both linear growth and weight increase²⁰⁴. However, the supplements did contain some micronutrients and thus the intake of these covaried with energy intake. Moreover, the supplemented children remained severely stunted, even though many of them consumed more energy than their requirements and their protein intakes were two to three times higher than recommendations²⁰⁵. In the Nutrition Collaborative Research Support Programme (CRSP), linear growth faltering was prevalent in preschool children in Egypt, Kenya and Mexico, even though their intakes of protein and essential amino acids were adequate²⁰².

The preceding discussion does not mean that protein intake is always adequate in the period of complementary feeding. Situations that contribute to a low protein intake are: low breastmilk intake; the use of low protein, starchy staples, such as cassava;

overreliance on foods high in sugars and fats; and low food intake in general.

Processed Complementary Foods

Starting in the 1960s, and up to the 1980s, there was considerable interest in developing and testing mixtures of ingredients, especially cereals and legumes that would improve the quantity and quality of protein in complementary foods. For example, this was a major focus for the Protein Advisory Group of the United Nations, which advised agencies, such as UNICEF, on appropriate formulations. Some of these weaning foods were designed, processed, mixed and packaged at the country level; e.g., *Incaparina* in Guatemala made from processed corn and cotton seed flour, vitamins and minerals; and *Thripasha* in Sri Lanka, made from corn and soybeans. Others were developed in the community (e.g., weaning formulas in Thailand prepared from roasted rice, beans, plus ground nuts or sesame) or at home (e.g., *Sarbottam Pitho* made from roasted legumes, wheat and/or corn and/or rice in Nepal)²⁰⁶. In addition to combining cereals and legumes, these complementary formulations usually recommended the addition of fruit and vegetables in the home, to provide nutrients such as vitamins A and C. However, there was little attempt to estimate and to provide the required amounts of micronutrients.

The earlier formulations met with limited success. Problems encountered included: relatively high cost for many households, especially those with the most undernourished children; lack of availability in rural areas; poor marketing; and sometimes, poor texture or flavour. Also, the importance of micronutrients for child growth and development had not been recognized, so that these mixtures tended to be nutritionally incomplete.

There has been some resurgence of interest in promoting processed, complementary foods²⁰⁷. Reasons for this include: the trend to urbanization, which creates demand for purchased foods that are easy and quick to prepare; the availability of improved, simple technology for production of blended cereals at the community level, which lowers the cost and improves the sustainability of supply; and the ability to fortify these foods with micronutrients. Production of such foods can generate income for women. The cost of buying fortified products to improve dietary quality may be less than adding other foods, such as animal products.

These foods should not be promoted for use by infants less than 6 months old if there is any risk that they will interfere with breastfeeding. The desirable characteristics of processed complementary foods

have been described by several authors; e.g.^{208,209}. The nutrient content (protein, fat, and micronutrients) of processed foods varies widely and is often not consistent with the amounts or densities of nutrients such as those recommended in Tables 4 and 5. There is an urgent need to pay more attention to the composition of these foods and to the bioavailability of their micronutrients. Different formulations may be needed for younger infants (who have higher nutrient requirements per kg body weight) compared to older preschool children. The Codex Alimentarius states that fortified foods should contain at least two thirds of the recommended intake of specific micronutrients per 100 g of dry food²¹⁰.

Improving the Micronutrient Content (Quality) of Complementary Foods

For practical purposes, the term “poor dietary quality” usually implies that a diet is low in micronutrients and/or that the micronutrients are not well absorbed; i.e., poor bioavailability.

Increasing the Consumption of Animal Products

One strategy for improving the amount and bioavailability of micronutrients is to increase consumption of animal products. Animal products are high in most micronutrients, and many minerals and vitamins are better absorbed from milk, meat and eggs than they are from plant-derived foods. Unfortunately, children in developing countries often receive only small amounts of foods that contain animal products, if any. Most animal-based foods contain more fat than plant-based foods. This makes them more energy dense, as well as being a good source of fat soluble vitamins and essential fatty acids. Animal products usually contain more retinol, vitamins D and E, riboflavin, calcium and zinc per 100 kcal of energy content, and are the only source of vitamin B₁₂. Animal products are the only foods that have high enough iron, zinc, calcium and riboflavin densities to provide the daily requirements of these micronutrients in complementary foods. This is especially true between 6 and 12 months of age, when only liver can be consumed in amounts large enough to meet recommended iron intakes¹⁹¹. Some types of animal products (meat, fish, and poultry) contain more iron and zinc than cereals, and in a form which is several times more absorbable than in iron and zinc from plants^{211,212}. However, consumption of animal products is culturally unacceptable in some areas.

There has been interest in improving the quality of complementary foods by adding locally available

animal products, as well as specific fruits and vegetables, to the usual cereals, staples and legumes that are fed to young children in developing countries. A higher intake of animal products has been associated with better growth in some studies. In Peru, higher intakes of breastmilk, animal products in foods, and complementary foods in general all promoted growth between 12 and 15 months of age²⁰³. In rural Mexico, the main predictor of children’s size and growth between 18 and 30 months of age was maternal size and the children’s intake of animal products²¹³. The smallest children had the smallest mothers and the lowest intake of animal products. In Kenya and Egypt, animal products were also predictors of available zinc, iron, and vitamin B₁₂ intakes, as well as child size and growth²¹⁴.

A dramatic example of the effects of withholding animal products from infants and young children is provided by studies of macrobiotic diets in the Netherlands. This example is particularly valuable because macrobiotic diets are somewhat similar to the diets of children in developing countries, and indeed are better than many. They consist primarily of cereals (mainly rice), vegetables, legumes, and marine algae, small amounts of cooked fruit and occasional fish. No meat or dairy products are used. Compared to omnivorous controls, the Dutch macrobiotic children consumed less protein, fat, calcium, riboflavin, vitamin B₁₂ and vitamin C. The adverse effects of these diets were clear even though these children were raised in sanitary environments and relatively good socioeconomic conditions. Birthweights were about 3,290 g in the macrobiotic group, significantly lower than the 3470 g in the controls. Birthweights were related to the household’s usual consumption of fish and dairy products. The growth of children on macrobiotic diets followed the reference line until 4 months, at which point length gain declined dramatically (to a rate of 13.2 cm/year compared to 16.7 cm/year in controls) until it stabilized at 16 months²¹⁵. There was no later catch-up. Weight gain followed a similar pattern but there was some catch-up after 2 years. WH was normal. Children from families consuming dairy products three times a week grew better than those who rarely consumed them. The macrobiotic infants showed numerous biochemical abnormalities and nutrient deficiencies, including: iron, with consequent anaemia; riboflavin deficiency; rickets; and vitamin B₁₂ deficiency²¹⁶. Their gross motor development, speech and language development were delayed²¹⁷. Recent publications show that the vitamin B₁₂ status and cognitive function of these children was still impaired in early adolescence, in spite of the fact that parents heeded advice to feed animal products, starting at 6 years on average²¹⁸.

Due to their good acceptability by infants and children, and their relatively low cost, milk products have often been provided to young children in order to improve the quality of their diets. In 12 out of 15 intervention trials (Table 6), consumption of milk resulted in improved growth relative to controls²¹⁹. Another approach has been the addition of locally available animal products to plant-based diets. However, the addition of dry fish powder to a fermented maize porridge, or to a blend of beans, groundnuts, and maize did not improve the growth or micronutrient status of Ghanaian children who were given these foods between 6 and 12 months of age²²⁰.

Given the poor economic situation of many households in developing countries, is it reasonable to recommend that their children consume more animal products? For some, this may not be a practical solution. There is, however, increasing awareness that animal products are likely to be the only unfortified foods that can provide enough micronutrients to children, and that it is feasible to increase their consumption. Viable strategies, in many situations, include: educating the mother to target small amounts of animal products (such as liver) to her youngest children; encouraging consumption of cheaper animal products (e.g., eggs, fish, dried milk); and supporting home production of small animals, fish and birds. Additionally, fermented milk products may be an excellent source of nutrients for children, and are more amenable than fresh milk to non-refrigerated storage.

Improving the Content and Bioavailability of Nutrients in Plant-Based Complementary Foods

The micronutrients that are most difficult to obtain in sufficient quantity from complementary foods in general, and especially from plant-based complementary foods, are: absorbable iron and zinc; calcium; vitamin A; and sometimes riboflavin. Vitamin B₁₂ is found only in animal products and breastmilk. Efforts are ongoing to increase the bioavailability of iron and zinc from complementary foods, using techniques such as germination and fermentation, to reduce the content of phytates. For example, these are being evaluated in Malawi (R. Gibson, personal communication).

Giving infants and young children coffee or tea to drink can have an adverse effect on iron status, because these drinks contain polyphenols that inhibit iron absorption. In a controlled intervention trial in Guatemala, discontinuing the usual coffee intake of preschool children improved their response to iron supplements²²¹. If teas are given to young children

between meals, there is less interference with iron absorption if they are given with meals.

The absorption of iron from cereals and legumes can be improved by consuming more vitamin C in the same meal. The implications of this interaction for complementary feeding have been described as follows²²². The vitamin C should be included in or given with the meals which contain most iron, or consumed within an hour of such meals. The addition to, or fortification of, a meal with 50 mg vitamin C approximately doubles the amount of iron that an infant can absorb. It may be difficult to provide this amount of vitamin C from fruit, juices or vegetables, but even smaller amounts will cause some improvement in iron absorption. Vitamin C produces the greatest increase in iron absorption when complementary foods (e.g., soy, whole maize, lentils, unpolished rice) are high in inhibitors such as phytates, but obviously has little effect if the foods are low in iron. The iron status of infants will improve if vitamin C is added to iron-fortified, formulated infant foods or dry milk²²³.

Risk factors for the early onset of VAD in infancy and childhood include: early weaning or a low intake of breastmilk; poor vitamin A status of the mother and subsequently low concentrations of the vitamin in breastmilk; and low intake of animal products rich in retinol²²⁴. However, the vitamin A requirements of infants and young children can be met from plant sources alone²²⁵. Dark green, leafy vegetables are less effective, although useful, sources of vitamin A, because their beta-carotene is less well absorbed than that of fruit²²⁶. Food-based interventions that have successfully improved vitamin A status are reviewed below in the section on Preventing and Treating Vitamin A Deficiency.

Fortification of Complementary Foods with Micronutrients

It is difficult to meet all of the micronutrient needs of infants and young children through home-based foods. A review of 23 complementary food combinations used in developing countries, including some animal products, revealed that although most of them could supply enough energy and protein, none had enough iron and few had enough zinc²²⁷. Animal products supply more of these nutrients but only few, such as liver, have a high enough densities to meet requirements¹⁹¹. Even in developed countries, the diets of young children would be too low in iron without supplementation; and therefore many cereals and other complementary foods are fortified with iron, even where diets are usually of high quality. Iron deficiency anaemia (IDA) is still a problem for infants in many developed countries²²⁸.

TABLE 6: Intervention trials with complementary foods

REGION	N	Initial age (months)	Duration of Intervention (months)	Intervention	Impact on Growth	Impact on Micronutrient Status
AFRICA						
Sudan ^a	628	6-26	3-6	DSM vs. beans	+ height (DSM group)	NA
D.R.Congo ^b	120	4	3	V/M fortified blend (cereal, soy, milk, oil) vs. none	NS	NA
Ghana ^c	208	6	6	Weanmix, Weanmix with V/M, Weanmix with fish powder, fermented maize with fish powder vs. cross-sectional comparison group	NS among intervention groups; + weight & + height in intervention groups vs. comparison group	+ Vit A + ferritin (in V/M group only); NS (Hb, riboflavin, Zn)
Sénégal ^c	110	4	3	V/M fortified blend (cereal, soy, milk, oil) vs. none	+ height	NA
ASIA-PACIFIC						
Indonesia ^d	113	6-20	3	High energy snacks	+ weight; NS height	NA
New Caledonia ^c	90	4	3	V/M fortified blend (cereal, soy, milk, oil) vs. none	NS	NA
Papua New Guinea ^e	43	6-12	12	DSM, peanut butter, soy or none	NS	+Hb (DSM group)
People's Republic of China ^f	164	6-13	3	V/M fortified vs. unfortified rusk	NS	+Hb - Vitamin E
Thailand ^g	205	<36	12	High fat biscuit, V/M fortified	NS	NS (Vitamin A, riboflavin, Fe and indices)
EUROPE						
Denmark ^h	41	8	2	High-meat vs. low-meat foods	NS	+ Hb; NS (Fe and Zn indices)
LATIN AMERICA						
Colombia ⁱ	170	Trimester III	39	DSM, with high protein vegetable mix, Fe, and vitamin A	+ height from 6 mo, + weight from 3 mo	NA
Guatemala ^j	330	3	33	"Incaparina" (cereal, legumes, milk) vs. sugar drink (some V/M in both)	+ height, + weight	NA
Jamaica ^k	127	9-24	12	Milk formula + DSM vs. none	+ height, + weight, + head circumference	NA
Bolivia ^c	127	4	3	V/M fortified blend (cereal, soy, milk, oil) vs. none	NS	NA

Sources: Adapted from Brown KH, Dewey KG, Allen LH (1998) Complementary feeding of young children in developing countries: A review of current scientific knowledge. Geneva: WHO; and Dewey KG (2001). Approaches for improving complementary feeding of infants and young children. Background paper for the WHO/UNICEF Technical Consultation on Infant and Young Child Feeding. Geneva: WHO. (In press). Additional sources are:

- ^a Vaughan JP, Zimwari F, Waterlow JC, Kirkwood BR (1981) An evaluation of dried skimmed milk on children's growth in Khartoum province, Sudan. *Nutrition Research* 1:243-252.
- ^b Simononon KB, Garner A, Berger J, Cornu A, Massamba JP, San Miguel JL, Coudy L, Misote I, Simononon F, Delpeuch F, Traissac P, Maire B (1996) Effect of early, short-term supplementation on weight and linear growth of 4-7-mo-old infants in developing countries: A four-country randomized trial. *American Journal of Clinical Nutrition* 64: 537-545.
- ^c Lartey A, Manu A, Brown KH, Pearson JM, Dewey KG (1999) A randomized, community-based trial of the effects of improved, centrally processed complementary foods on growth and micronutrient status of Ghanaian infants from 6 to 12 mo of age. *American Journal of Clinical Nutrition* 70: 391-404.
- ^d Husaini MA, Karyadi L, Husein Sandjaja YK, Karyadi D, Pollitt E (1991) Developmental effects of short-term supplementary feeding in nutritionally-at-risk Indonesian infants. *American Journal of Clinical Nutrition* 54: 799-804.
- ^e Becroft T, Bailey KV (1965) Supplementary feeding trial in New Guinea highland infants. *Journal of Tropical Pediatrics and African Child Health* 11:28-34.
- ^f Liu DS, Bates CJ, Yin TA, Wang XB, Lu CQ (1993) Nutritional efficacy of a fortified weaning rusk in a rural area near Beijing. *American Journal of Clinical Nutrition* 57: 506-511.
- ^g Gershoff SN, McGandy RB, Nondasuta A, Tantivongse P (1988) Nutrition studies in Thailand: effects of calories, nutrient supplements, and health interventions on growth of preschool Thai village children. *American Journal of Clinical Nutrition* 48: 1214-1218.
- ^h Engelmann MDM, Sandstrom B, Michaelsen KF (1998) Meat intake and iron status in late infancy: An intervention study. *European Journal of Clinical Nutrition* 67: 26-33.
- ⁱ Lutter CK, Mora JO, Habicht J-P, Rasmussen KM, Robson DS, Herrera MG (1990) Age-specific responsiveness of weight and length to nutritional supplementation. *American Journal of Clinical Nutrition* 51: 359-364; and Mora J, de Paredes B, Wägener M, de Navarro L, Suescun J, Christiansen N, Herrera MG (1979) Nutritional supplementation and the outcome of pregnancy. I. Birthweight. *American Journal of Clinical Nutrition* 32: 455-462.
- ^j Martorell R, Habicht J-P, Rivera JA (1995) History and design of the INCAP longitudinal study (1969-77) and its follow-up (1988-89). *Journal of Nutrition* 125: 1027S-1041S; and Schroeder DG, Martorell R, Rivera JA, Ruel MT, Habicht J-P (1995) Age differences in the impact of nutritional supplementation on growth. *Journal of Nutrition* 125: 1051S-1059S.
- ^k Walker SP, Powell CA, Grantham-McGregor SM, Himes JH, Chang SM (1991) Nutritional supplementation, psychosocial stimulation, and growth of stunted children: The Jamaican study. *American Journal of Clinical Nutrition* 54: 642-648.

Efficacy Trials of Complementary Foods

Randomized trials of the effects of processed complementary foods on nutrition status and development have produced mixed results. Most trials involved infants between 6 and 12 months of age. The results of trials published since 1988 were summarized in the WHO report¹⁹¹ and newer trials have also been summarized by Dewey¹⁶⁸ (Table 6).

The trials reviewed in the two reports were conducted in Papua New Guinea²²⁹, Sudan²³⁰, Thailand²³¹; Colombia²³²; Guatemala^{156,233}; Indonesia²³⁴; Jamaica²³⁵; PRC²³⁶, Bolivia, the D.R. Congo, New Caledonia and Sénégal²³⁷, Ghana²²⁰, and Denmark²³⁸. The overall conclusions derived from these trials include the following:

- The trials varied considerably in terms of the age at which the intervention occurred, the composition of the complementary foods, the baseline nutritional status of the infants; and the extent of breastfeeding.
- In three trials (Guatemala, Colombia and Jamaica) the supplement increased weight and length; in Indonesia and Sénégal, only weight was increased.
- Most of the supplements contained dry milk, with or without cereals. There was no obvious relationship between composition and outcomes.
- The critical age for intervention appears to be between 6 and 12 months, with diminishing benefit during the next 1 to 2 years.
- The supplemental foods provided a substantial amount of energy, on average twice the amount that was actually consumed by the infants (intake was 120 to 458 kcal/day). Displacement of breastmilk, and therefore net increase in energy intake, was not measured in any of the studies. Displacement is more likely when the complementary foods are given prior to six months of age²³⁹, and may explain the lack of response of infants supplemented from 4 to 7 months in the D.R. Congo, and the positive response of already-weaned infants in Jamaica and Colombia.
- Some trials provided foods to the mother during pregnancy, then to the child. There is some evidence that infants born to women supplemented during pregnancy have greater weight and length gains even before they themselves start consuming the complementary food^{240,241}, but more studies are needed to confirm this possibility.
- Few studies provided adequate micronutrients or assessed the impact on micronutrient status.

Multiple micronutrient fortification or supplementation had variable effects on status in the few studies in it was measured.

- Hb was increased by unfortified foods alone in Papua New Guinea, the PRC, Denmark, Vietnam and The Gambia, but not in Ghana.
- In none of the studies reviewed for the WHO report¹⁹¹ did children attain the expected growth velocity for age. This was not checked for the remainder of the studies. There are many possible reasons for this including the long term effects of *in utero* undernutrition.

Micronutrient Supplementation to Improve Growth

There have been numerous randomized, placebo-controlled trials of the effects of single nutrient supplements on the nutrition status and development of infants and children. To the extent that they are actually consumed, supplements improve, in most cases, the body stores of the specific micronutrient. The most important question is whether such supplementation improves functional outcomes: such as growth, vision (in the case of vitamin A), morbidity or mortality, or cognitive and motor development. The following discussion primarily deals with the impact of supplements on growth. The impacts of iron and vitamin A supplements on other functions are reviewed further in the sections on Preventing and Treating Anaemia and Preventing and Treating Vitamin A Deficiency.

Iron

In developing countries, iron deficiency occurs early in infancy, and approximately 50% of infants are iron deficient by the end of their first year of life¹¹. This may be an overestimate, based on recent data indicating that the Hb cut-off indicating anaemia in infants is set too high²⁴². Nevertheless, there is ample evidence that iron deficiency is common during infancy. There is mixed evidence for an improvement in growth of anaemic preschool and school children when they are given iron supplementation. Iron supplements increased the weight gain of anaemic children in four studies in Indonesia, Kenya, and the USA²⁴³. Height gain was not measured in two of the studies. It was significantly improved in one, and not improved in the other. One possible explanation for this inconsistency is that the studies were too short to detect effects on linear growth. They were designed to measure rapid changes in Hb concentrations.

For infants, recent placebo-controlled intervention trials in Sweden and Honduras found that iron

supplementation from age 4 to 9 months (1 mg/kg/day; i.e., half the dose recommended by WHO for infants age 6 to 24 months) significantly reduced length gain (on average by 0.4 cm) during this period²⁴⁴. Iron-supplemented infants who had higher baseline ferritin concentrations (>60 µg/L) had more diarrhoea than those in the placebo group. Clearly more work is needed in this area before routine iron supplementation for young infants can be recommended.

Zinc

Zinc deficiency is probably widespread in developing countries, although its prevalence is uncertain due to a lack of simple status indicators. It is caused by: low intakes of animal products; diets high in phytates, which inhibit zinc absorption; and losses due to diarrhoea. Randomized, controlled trials of zinc supplementation for children have produced varying degrees of growth response. For example, short children in the USA grew faster when supplemented with 5 mg zinc/day for 12 months²⁴⁵, and 3- to 5-year-old children in rural Ecuador responded to 10 mg/day zinc with faster height gain within six months²⁴⁶. Stunted Guatemalan infants also responded to zinc supplements with faster linear growth²⁴⁷. In contrast, a trial that provided 20 mg/day zinc to preschool children in rural Mexico for 12 months found no improvement in weight or height²⁴⁸. A meta-analysis of 25 studies revealed that there was an overall small, but highly significant, impact of zinc supplements on height, but only in children with initial HA Z-scores less than -2.0²⁴⁹. Weight also increased slightly yet significantly, but only in those children with initially low plasma zinc concentrations. No variations were detected in response due to age at treatment. There may be other benefits of zinc supplementation for children, including: a reduction in the duration and severity of diarrhoea, observed in Guatemala, India, Mexico, Papua New Guinea, Peru and Viet Nam²⁵⁰; persistent diarrhoea and dysentery, in India²⁵¹; and acute lower respiratory infections, in India²⁵².

Vitamin A

Supplementation of infants and children less than 5 years old with vitamin A is routinely achieved in most developing countries by administration of oral capsules, often delivered through the Expanded Programme on Immunization (EPI) of WHO, and through "National Vitamin A Days"²⁵³. This reduces ocular symptoms of vitamin A deficiency, as well as mortality from measles²⁵⁴, and improves Hb synthesis. However, randomized, controlled trials in Peru,

Ghana and India failed to show any benefit on mortality or morbidity, of providing high doses of vitamin A through the EPI during infancy. Moreover, the vitamin A status of the infants was little improved²⁵⁵. The doses of vitamin A provided may have been too low²⁵⁶.

Children with mild xerophthalmia in West Java, Indonesia had slower rates of weight and height gains than nonxerophthalmic children²⁵⁷. This and other observations have suggested that modest improvements in growth might be an additional benefit from vitamin A supplementation of deficient children. This has been observed in some randomized, controlled studies^{258, 259}, but not in all e.g.,^{260, 261, 262}. In a recent Indonesian trial, only children with initially low serum retinol concentrations (<0.35 µmol/l) responded to a supplement of 100,000 IU to 200,000 IU of vitamin A²⁶³. In the 4 month intervention, the supplemented children's height and weight gain were, on average, 0.39 cm and 152 g more than those in the placebo group. Children younger than 24 months responded only if they were consuming no vitamin A from breastmilk. It appears that vitamin A status may affect linear growth. The conflicting results among studies might be explained by failures to take into account the initial vitamin A status of supplemented children and the extent of deficiencies of other micronutrients required for growth. Improving vitamin A status is justified, however, even if it does not improve growth.

Calcium

A review of calcium intervention studies²⁶⁴, found that four out of six failed to find an impact on growth. The two trials with a positive effect were conducted 60 years ago in a school for children of low to middle socioeconomic status, in India. The children were aged 3 to 6 years, and 6- to 12 years²⁶⁵. Most calcium intervention studies have been done on prepubescent children. Even in 8- to 12-year-old school children who were consuming very small amounts of calcium (average, 342 mg/day) in The Gambia, increasing calcium intake to 1,056 mg/day, through supplements for 12 months, caused no improvement in weight or height gain compared to a placebo group²⁶⁶. However, the supplemented children did improve their bone mineral content and had lower serum osteocalcin, indicating reduced bone resorption. Current thinking is that bone mineralization during growth is the major determinant of peak bone mineral content in adulthood, and that this protects against osteoporosis in later life. Concern about adequate calcium intakes in childhood is certainly justified, even if these do not affect growth.

Iodine

Severe iodine deficiency causes substantial linear growth retardation. Marginal deficiency is associated with shorter stature²⁶⁷. Some of the associations seen in early childhood might be explained by a residual effect of poor maternal iodine status during pregnancy, which reduces birthweight. The provision of iodized oil prior to conception increases birthweight²⁶⁸. However, growth was not restored to normal when iodized oil was given to children in a region of Ecuador with endemic iodine deficiency²⁶⁹ or to goitrous school children in Bolivia²⁷⁰. As discussed further below, the other benefits of iodine supplementation of deficient infants and children include reduction in the spectrum of IDD and in infant mortality.

Multiple Micronutrients

Single micronutrient deficiencies are probably unlikely in children aged less than 3 to 5 years^{271, 272}, and several micronutrient deficiencies are implicated in growth failure. It is therefore reasonable to assume that supplements containing multiple micronutrients will have the largest impacts on growth and function. There is currently substantial interest by international organizations, such as UNICEF and WHO, in testing the effects of multiple micronutrient supplements. As is true in the case of supplementation with iron alone, the main limitations to their adoption seem to be programmatic, such as delivery and compliance, rather than cost. The additional micronutrients add little to the overall price of supplements. A multiple micronutrient supplement might be more attractive to consumers than an iron supplement alone. However, some micronutrients need to be consumed daily or every few days in order to improve status; whereas iron, vitamin A and folic acid supplements may improve nutrient status if taken once a week.

Several multiple micronutrient formulations, appropriate for children during the period of complementary feeding are now being tested in malnourished populations, though relatively few trials have been completed and published. In Viet Nam, multiple micronutrient supplements (containing iron, vitamins A and C and zinc) improved the rate of linear growth and reduced anaemia in preschool children, when given for 3 months either weekly or as a larger dose three times per week²⁷³. The iron, vitamin A and zinc status of the supplemented children was also better than that of the controls, who received iron supplements only. In Mexico, children aged 8 to 14 months were randomly assigned to a multiple micronutrient supplement or a placebo for 12 months²⁷⁴. There was no significant effect on weight.

Length gain was 0.3 Z greater in the supplemented children, but only if they were less than 12 months of age at the start of the intervention. In Peru, a trial compared supplements that contained zinc alone with supplements providing zinc and micronutrients²⁷⁵. The inclusion of micronutrients appeared to increase the relative risk of dysentery, whereas zinc alone reduced the prevalence of cough. In Guatemala, infants were randomly assigned to one of four groups for 8 months, starting around 6 months of age. The treatment groups were given: multiple micronutrients with whey protein concentrate; multiple micronutrients with bovine serum concentrate; bovine serum concentrate alone; and whey protein concentrate alone. There were no differences in length gain among the groups²⁷⁶. Further trials with multiple micronutrient supplements for young children are in progress in South Africa, Peru and Indonesia, using a new supplement formulated by UNICEF and other agencies.

A novel product that shows potential is a fat-based spread that contains multiple micronutrients (Nutraset, Paris, France). This product has been useful in emergency relief situations and for recovery of malnourished children²⁷⁷. Further efficacy trials with such products are urgently needed. The advantages of Nutraset include: very low water content, which reduces interactions among micronutrients as well as bacterial growth; high acceptability by preschool children (infants have not yet been tested); high energy density; improved carotene and fat soluble vitamin absorption, due to its fat content; and the fact that enzymes such as amylase can be added to reduce viscosity when the product is added to cereals. Its production does not require sophisticated technology and it can be produced locally, using foods such as peanuts as the base. It is available in single serving sachets, as well as in larger containers.

The micronutrient spread has been tested for its effects on catch-up growth and anaemia in children living in a permanent refugee camp in Algeria²⁷⁸. Prior to supplementation, this population was dependent on rations (predominantly wheat flour, rice, other cereals, and a small amount of canned fish) that provided slightly more than half of the energy and protein requirements for adults, slightly under half of their iron, vitamin C and thiamine requirements, and 6% of their vitamin A requirements. The intervention was targeted to stunted children (HA below -2 Z-scores). For 6 months, 364 children, aged 30 to 64 months, were provided daily with 50 g of the fortified supplement, or the supplement without micronutrients, or nothing (controls). All the children were treated for parasites with metronidazole. The 50 g of supplement provided about 300 kcal and 5 g

TABLE 7: Interventions with multiple micronutrients

Country	N	Initial age (months)	Duration of Intervention (months)	Interventions	Impact on Growth	Impact(s) on micro nutrient status
The Gambia ^a	125	6-18	12	Fe + vits; Zn + vitamins; vitamins only; none	ns	+ Hb
Guatemala ^b	259	6	8	BSC + V/M, V/M, BSC or placebo	ns	ns
Mexico ^c	319	8-14	12	V/M vs. placebo	+ height (in children aged < 12 months initially)	(vitamins A and E)
Peru ^d	412	6-36	6	Zn + V/M, Zn alone, or placebo	ns	nr nr
Viet Nam ^e	163	6-24	3	Fe, Zn, and vitamins A and C, weekly or daily, or placebo	+ height (only in stunted children)	+ Hb, + vitamin A, + Zn

Sources: ^a Lartey A, Manu A, Brown KH, Peerson JM, Dewey KG (1999) A randomized, community-based trial of the effects of improved, centrally processed complementary foods on growth and micronutrient status of Ghanaian infants from 6 to 12 mo of age. *American Journal of Clinical Nutrition* 70: 391-404.

^b Brown KH, Santizo MC, Begin F, Torun B (2000) Effect of supplementation with multiple micronutrients and/or bovine serum concentrate on the growth of low-income, peri-urban Guatemalan infants and young children. *Federation of American Societies for Experimental Biology Journal* 14: A534.

^c Rivera JA, Gonzales-Cossio T, Flores M (2001). Multiple micronutrient supplementation improves the growth of Mexican infants. (Submitted for publication). *American Journal of Clinical Nutrition*. (In press).

^d Penny ME, Brown KH, Lanata CL, Peerson JM, Marin RM, Duran A, Lonnerdal B, Black RE (1997) Community-based trial of the effect of zinc supplements with and without other micronutrients on the duration of persistent diarrhoea, and the prevention of subsequent morbidity. *Federation of American Societies for Experimental Biology Journal* 11: A655.

^e Thu BD, Schultink W, Dillon D, Gross R, Leswara ND, Khoi HH (1999) Effect of daily and weekly micronutrient supplementation on micronutrient deficiencies and growth in young Vietnamese children. *American Journal of Clinical Nutrition* 69: 80-86.

Notes: BSC = bovine serum concentrate; Hb = haemoglobin; N = Sample population size; ns = not significant; nr = not yet reported; + = increased; V/M = vitamin and mineral.

protein/day; substantial daily amounts of iron (11 mg) and zinc (about 10 mg), and about half the daily requirements for calcium and the major vitamins and minerals, except for vitamin A. The supplement contained no vitamin A, which was instead provided in capsules. The height velocity in those receiving the fortified supplement was about 6 mm/month: significantly higher than for those receiving unfortified supplement or no supplement at all (5 mm/month). The prevalence of anaemia fell from about 75% initially to less than 10% in the fortified supplement, but remained above 50% in the unfortified and control groups. There were significant reductions in diarrhoea, acute respiratory infections and fever episodes in the supplemented children.

The positive impact of this study may have been influenced by the following. The children were initially stunted, anaemic, and presumably deficient in multiple micronutrients. They liked the supplement very much, so compliance was high. Moreover, its consumption was supervised. The supplement supplied substantial amounts of micronutrients and the intervention lasted for 6 months. Importantly, only the micronutrient-fortified supplement, and not the macronutrients in an equivalent amount of unfortified supplement, was effective at improving growth and reducing anaemia.

A novel strategy that is being developed and tested is the use of micronutrient "sprinkles". These are vitamin-mineral mixtures in which the micronutrients

have been encapsulated, or coated with lipids or other substances, to reduce adverse interactions among the nutrients (for example, iron can destroy vitamins A and E in a mixture of these nutrients). Sprinkles are available in single-dose sachets that can be added once a day to any food or liquid given to the infant. Iodine, iron, vitamin A, and zinc can be combined in this way. In Ghana, a trial of this approach, in anaemic 6- to 24-month-old children, concluded that iron added to food in sprinkles (which contained iron and vitamin C) was as available as that in ferrous sulphate drops (S. Zlotkin, personal communication). Further trials are underway with additional micronutrients and the measurement of functional outcomes.

Summary and Conclusions

South Central Asia has the second highest prevalence of growth stunting in the world (44%), and the prevalence in South-East Asia is also high (33%). An estimated 70% of the world's stunted children live in Asia, and there has been little recent improvement in the situation. Growth stunting in childhood is a risk factor for increased mortality, poor cognitive and motor development and other impairments in function. It usually persists, causing smaller size and poorer performance in adulthood. Nutrition intervention trials support the following recommendations.

- Exclusive breastfeeding is strongly recommended for the first 6 months of life.
- There is probably no advantage to the infant of introducing complementary foods prior to 6 months, especially where the quantity and quality of such foods is inadequate.
- Breastfeeding should be continued when other foods are added to the infants diet. In general the quality of complementary foods is poor compared to breastmilk.
- The energy density of many gruels, soups, broths, and other watery foods fed to infants is often below the recommended 0.6 kcal/g. Energy intake can be increased by reducing the water added to foods where possible, and/or providing additional feedings. At present there is insufficient evidence to promote the use of amylases to lower the viscosity of cereals. Adding extra energy in the form of oil or sugar can adversely affect the density of protein and micronutrients in the diet.
- Even where breastmilk intake is relatively low, in most situations the amount of protein in complementary foods will be more than adequate so that adding protein alone or improving protein quality will not improve growth.
- Randomized controlled trials of the effects of processed complementary foods have shown a mixed impact on growth. Most of the trials included infants 6 to 12 months. In three, the supplement increased weight and length; in two (including Indonesia) only weight was improved; and in another four (including Thailand) there was no effect on growth. In no study did children attain the expected growth velocity for age.
- Intervention after 12 months is less effective than between 6 and 12 months. However, there is an increased risk of displacement of breastmilk when intakes of complementary foods are high, especially before 6 months of age.
- Limitations of these trials include variability in the age at which the intervention started, the composition of the foods and the amounts provided, the extent and replacement of breastmilk, and the baseline nutritional status and morbidity of the infants. Few of these complementary feeding trials supplied enough micronutrients to permit the child to consume recommended intakes from the diet plus supplements.
- In most developing countries and even in wealthier regions, the micronutrient content of unfortified complementary foods is inadequate to meet infant requirements. It is particularly difficult for infants to consume enough iron, zinc, or calcium, and vitamin A, riboflavin, thiamine and vitamin B₆ intakes are often low. The intake of vitamin B₁₂ will be inadequate if maternal deficiency has reduced breastmilk concentrations and the infant consumes low amounts of animal products.
- Interventions with single micronutrients have shown the following benefits for children with low intakes and/or a deficiency of the respective nutrients: vitamin A prevents eye lesions, causes a substantial reduction in mortality from measles and diarrhoea, and increases Hb synthesis; iron improves cognitive and motor development of anaemic infants and children; zinc improves growth of children who are stunted or have low plasma zinc; iodine reduces infant mortality and goitre prevalence and improves motor and mental function; vitamin B₁₂ improves growth and cognitive function.
- Because multiple micronutrient deficiencies tend to occur simultaneously, there is interest in the benefits of providing supplements that contain multiple micronutrients. Multiple micronutrient supplements caused some improvement in height growth rate in stunted Vietnamese children and in Mexican infants aged <12 months, but had no impact on growth in Peru or Guatemala.

Additional trials are underway to confirm whether multiple micronutrients improve child nutritional status, health and development more than single micronutrients. Novel approaches to providing multiple micronutrients include a fat-based spread which improved growth and Hb in one trial in stunted children, and encapsulated “sprinkles” which are undergoing further trials.

- Micronutrient intake can also be improved by targeting animal products to young children. The consumption of higher amounts of animal products was associated with better growth and micronutrient status in several studies. A review of 15 complementary feeding trials in which dried

milk was included as at least one ingredient revealed that growth in length was significantly increased in 12 of these. The control groups either received no intervention, energy or some micronutrients. The one trial with dry fish powder showed no benefits of adding it to fermented maize. Increasing meat intake improved Hb in Danish infants. Meats such as chicken liver could be rich micronutrient sources for infants and children, but controlled trials of their efficacy are lacking.

- Micronutrient fortification of cereal staples is especially important where these are major constituents of complementary foods.

