4. Protein and micronutrients required from complementary foods

Section 3 described the approach for estimating the energy content of breast milk consumed at various ages, and the corresponding energy content of complementary foods that are needed to meet the daily energy requirements of the child. In this section we follow the same logical process to derive estimates of the desired intake of protein and micronutrients from complementary foods. Current information on the importance of protein and micronutrients for the prevention of growth-faltering and associated delays in functional development is reviewed in sections 4.1 and 4.2. This is followed in section 4.3 by a summary of the micronutrient composition of breast milk, including a discussion of how this might differ in developing countries as a result of maternal micronutrient deficiencies. Section 4.4 presents recommended protein and micronutrient intakes for infants and young children. The desired micronutrient content of complementary foods (expressed in terms of micronutrient density, i.e. amount of each micronutrient/kcal_{th} food) is then estimated (section 4.5.1) using the same general process that was used to calculate the desired energy content. However, numerous food constituents may affect the absorption of micronutrients from food; these are considered in section 4.5.2. Finally, food intake data from infants and children in Peru, Mexico and the United States of America are analysed (section 4.5.3 and 4.5.4) to examine whether the micronutrient densities and amounts of the non-breast-milk foods they consumed met, or could meet, their micronutrient requirements. Also, those nutrients that have a low density in foods relative to infants' requirements are identified.

4.1 Importance of protein and micronutrients for the prevention of growth-faltering

As described in section 2.2, in developing countries linear growth-faltering, compared to international reference values for length, is a common phenomenon in infants from low (but not higher) socioeconomic groups. The age of onset of linear growth-faltering has been reported to start as early as immediately after birth (Backstrand & Allen, 1996; Rivera & Ruel, 1997) or as late as six or more months of age (Dewey et al., 1992c). Linear growth-faltering typically continues until children are about 18-24 months of age, after which time stunted children grow at the same rate as those in industrialized countries. However, usually they fail to catch up to the size of the well-nourished reference children, although some reversal of stunting is certainly possible if there are marked improvements in their diet and environment (Golden 1994; Martorell, Kahn & Schroeder, 1994). To date, the relative contribution of different factors to growth-stunting in developing countries has not been studied systematically, and may vary between one location and the next. It is possible that *in utero* accumulation of micronutrients is poor in infants born to women with inadequate micronutrient stores or intake, and that subsequently these infants become depleted of these nutrients postpartum. This situation could be exacerbated if the concentrations of micronutrients are low in maternal milk, and if the quality or quantity of complementary foods is inadequate. Other factors that contribute to growth-stunting are the shorter stature of mothers in developing countries, and the high rate of morbidity that peaks during the first or second year of life.

Numerous intervention studies have been conducted with the goal of preventing growth-faltering, and to identify the specific nutrient deficiencies and other mechanisms that might be responsible for this phenomenon. More detail is available in a recent publication from a symposium on this topic (Waterlow & Schürch, 1994). The results of such studies are often conflicting, due to factors such as differences in the amount, duration and type of supplements among trials, the baseline nutritional status of the children, and the probable simultaneous occurrence of multiple nutrient deficiencies. In addition, many interventions occurred late in, or even after, the period of growth-faltering so although they could have improved "catch-up" growth, they could not have prevented growth failure. The following summary of our current knowledge about the role of protein, mineral and vitamin deficiencies in infant growth failure is restricted to nutrient deficiencies that are relatively common in developing countries, and which have the potential to impair growth.

Protein

The majority of evidence suggests that protein deficit is not typically a cause of growth-faltering in developing countries. There have been numerous investigations of the effect of feeding protein-rich foods such as milk, with or without other foods, to already stunted children. In some of these studies growth was improved, but in others it was not (Beaton & Ghassemi, 1982). Because protein-rich foods also have a high content of other nutrients such as iron, zinc, copper, calcium, and vitamins A, riboflavin and B_{12}, it is not possible to evaluate the specific role of protein in most studies. In the Institute of Nutrition of Central America and Panama (INCAP) longitudinal study in Guatemala, mothers and infants (generally from 4 months of age) were provided with supplements that contained either good-quality protein (based on dried skimmed milk and cereal), or energy without protein. Both types of supplement reduced growth-faltering but energy intake, not protein, was the main predictor of height and weight growth. However, both supplements contained micronutrients so that the actual nutrient(s) improving growth could not be identified definitively (Allen, 1994a). It is important to note that while the supplements did reduce growth-faltering, an effect that was limited to the first 2-3 years of life, the infants and children still remained severely stunted (Allen 1994a). The supplements met, and for some children exceeded, current recommendations for energy. Protein intakes were 2-3 times higher than requirements for most children. Thus, either the supplements were growth-limiting because of nutrient deficiencies other than energy or protein, or the stunting was due in part to other factors; however, diarrhoea was not found to account for the majority of growth-faltering (Martorell et al., 1975a). The INCAP conclusions were supported by the Nutrition Collaborative Research Support Program (CRSP), where growth-stunting was ubiquitous in Egyptian, Kenyan and Mexican infants, and preschoolers under 2 years of age, but the protein and essential amino acid intakes of preschoolers (aged 18-38 months) were more than adequate for virtually every child (Beaton, Calloway & Murphy, 1992).

In summary, low intakes of protein *per se* are probably not the cause of growth-faltering in most situations. As a cautionary note, this assumption is based primarily on the fact that in stunted populations children's dietary protein intakes seem to meet their protein and essential amino acid requirements. This generalization may not hold where complementary foods are based on staples with a low protein content, such as sweet potatoes or cassava, and are not supplemented with other protein-rich foods.

Zinc

Zinc deficiency has long been suspected to be prevalent in children in developing countries, particularly where diets are low in animal products and high in phytate (e.g. where they are based on maize, legumes, whole wheat especially if unleavened, or unpolished rice) (Sandstead, 1991). In addition, diarrhoea is an important cause of intestinal zinc loss (Castillo-Durán, Vial & Uauy, 1988).

Investigations of the impact of zinc supplements on the growth of infants and young children in developing countries have produced inconsistent results. For example, providing a zinc supplement of 10 mg/d to 3-5-year-old children in Ecuador produced significant increases in length within 6 months (Dirren et al., 1994), whereas 20 mg/d had no effect on the growth of rural 18-36-month-old Mexican children after 6 or 12 months of supplementation (Rosado et al., 1997).

The apparent discrepancy among the results of such studies has been resolved by a recent meta-analysis of data from existing prospective, placebo-controlled intervention trials (Brown, Peerson & Allen, in press). The original studies were published between 1974 and 1996, and include 1,834 children from most regions of the world. For all studies combined there was a small, highly statistically significant increase in length gain when zinc supplements were provided. When studies were classified according to the mean initial height-for-age Z-score (HAZ) of study participants, those in which the average child was stunted (HAZ < -2 SD) showed a moderately large response to zinc supplementation (0.5 SD), whereas those that included children with a higher mean initial HAZ showed no increase in growth following supplementation. The rate of weight gain was also increased by zinc supplementation, although this was limited primarily to those studies in which children had low initial plasma zinc concentrations. Several studies have also demonstrated that zinc supplementation increases rates of growth during recovery from severe malnutrition (Simmer et al., 1988; Khanum et al., 1988; Golden & Golden, 1992; Castillo-Duran et al., 1995). Thus, zinc supplementation has been found to have a positive impact on children's growth in a number of different situations in which physical growth is presently compromised.

Iron

Iron deficiency is probably even more prevalent than zinc deficiency. However, its role in growth-faltering remains uncertain (Pollitt, 1991). Few studies have reported an impact of iron supplements on length gain, although improvements in weight gain have been found more often (Allen, 1995). In one study of Kenyan school children, iron supplements improved appetite as assessed by the amount of energy consumed in a fixed meal, and doubled the rate of weight gain (Latham et al., 1990). Most iron supplementation trials last only 2-3 months, which is long enough to treat anaemia but perhaps not long enough to detect improved linear growth. However, even daily iron supplements for a year failed to increase the length or weight gain of anaemic, iron-deficient Mexican children aged 18-30 months (Rosado et al., 1997). Thus, at present we cannot rule out the possibility that iron deficiency impairs children's growth, but a definitive answer to this question awaits a meta-analysis of existing data, and additional longer-term studies that include younger, more anaemic infants.

Copper

The risk of copper deficiency is increased by low birth weight, low copper intake (e.g. due to feeding large amounts of cow's milk to infants to the exclusion of other foods), malabsorption and diarrhoea. There is little doubt that copper supplements improve the food intake and weight gain of some children recovering from severe malnutrition (Castillo-Duran & Uauy, 1988). Perhaps, because most of the supplementation trials were short, improvements in linear growth were either absent or not reported.

Calcium, phosphorus and magnesium

An analysis of quantitative food intake data revealed that children in developing countries have intakes of phosphorus and magnesium many times higher than estimated needs, while calcium intakes are close to requirements before any allowance for poor absorption (Prentice & Bates, 1994). Low calcium intakes in children may induce rickets, growth retardation, and biochemical signs of hyperparathyroidism that normalize after calcium supplementation. However, a review of available studies concluded that calcium supplements, alone or together with phosphorus, do not improve height or weight gain of children in developing countries with low-medium calcium intakes (Prentice & Bates, 1994). This was also found to be the case in the one study conducted on young children, aged 6-30 months (Bansal et al., 1964).

Iodine

Iodine deficiency is endemic in many regions of the world, and populations with marginal iodine deficiency are still being identified in regions such as central Asia, China, eastern Europe, and the Middle East. Severe iodine deficiency causes substantial linear growth retardation (Greene, 1980), which can be partly reversed by iodine supplementation even in adulthood. While there are fewer data on the impact of marginal deficiency, it also has been associated with stunting (Neumann, Bwibo & Sigman, 1992). Interventions to improve the iodine status of deficient women prior to conception have been found to improve birth weight (Chaouki & Benmiloud, 1994).

Vitamin A

The effects of vitamin A supplementation trials on weight gain or length gain have been inconsistent, even in vitamin A deficient populations. In general, it seems unlikely that this vitamin deficiency has a major effect on the growth of infants or children (Allen, 1995), but because there are isolated reports of improvement after supplementation, an effect cannot be ruled out without additional analyses that include attention to the type of intervention, the initial vitamin A status of the child, and the presence of other potentially confounding nutrient deficiencies.

4.2 Importance of micronutrients for anaemia prevention and other functions

Supplying adequate amounts of protein and micronutrients in complementary foods is also important for the prevention of other consequences of nutrient deficiencies, in addition to growth-faltering. Iron-deficiency anaemia becomes prevalent in developing countries as early as the first year of life, and even in industrialized countries fortification of infant foods with iron is deemed to be essential for preventing anaemia in childhood (Filer, 1989). As discussed in section 2.2.5, breast milk does not supply enough iron to meet iron requirements after 6-9 months of age, or earlier in infants who are premature or of low birth weight. Because iron-deficiency anaemia causes delays in neuropsychomotor development (Walter, 1993) and other functions (Filer, 1989; Vyas & Chandra, 1984), the provision of adequate amounts of iron through complementary foods is an important concern.

In addition to its importance in preventing growth-faltering, evidence is emerging that the provision of supplemental zinc to children in developing countries can reduce the incidence of diarrhoea (Ninh et al., 1996; Rosado et al., 1997; Ruel et al., 1997; Sazawal et al., 1996), the duration and severity of a diarrhoeal episode (Sazawal et al., 1995), and the incidence of dysentery (Sazawal et al., 1996).

Vitamin A deficiency not only causes eye damage manifested as night blindness and xerophthalmia, but increases the severity of, and risk of mortality from, infections such as measles (Beaton et al., 1993), and contributes to the development of anaemia (Mejia & Chew, 1988).

4.3 Protein and micronutrients in breast milk

4.3.1 Protein and micronutrient composition of breast milk

Information on the nutrient composition of mature (≥21 days postpartum) human milk is provided in Table 22. The data in this Table are taken primarily from the Institute of Medicine's report "Nutrition During Lactation" (Institute of Medicine, 1991), although we also examined information from more recent reviews and publications to ensure that there were no major changes in the previously summarized values. Values for vitamin A content were those published more recently by Underwood (1994) because they include more thorough estimates for the retinol concentration in human milk in developing countries.

Table 22. Estimated nutrient concentrations (mean±SD) in mature human milk[a]

Nutrient	Amount
Lactose (g/L)	72±2.5
Protein (g/L)	10.5±2.0
Fat (g/L)	39.0±4.0
Vitamins	
Biotin (µg/L)	4±1
Folate (µg/L)	85±37
Niacin (mg/L)	1.50±0.20
Pantothenic Acid (mg/L)	1.80±0.20
Riboflavin (mg/L)	0.35±0.025
Thiamin (mg/L)	0.21±0.03
Vitamin B_6 (µg/L)	93±8
Vitamin B_{12} (µg/L)	0.97
Vitamin C (mg/L)	40±10
Vitamin A (µg RE/L)[b]	500[b]
Vitamin D (µg/L)	0.55±0.10
Vitamin E (mg/L)	2.3±1.0
Vitamin K (µg/L)	2.1±0.1
Minerals	
Calcium (mg/L)	280±26
Chloride (mg/L)	420±60
Chromium (µg/L)	50±5
Copper (mg/L)	0.25±0.03
Fluoride (µg/L)	16±5
Iodine (µg/L)	110±40
Iron (mg/L)	0.30±0.10
Magnesium (mg/L)	35±2
Manganese (µg/L)	6±2
Phosphorus (mg/L)	140±22
Potassium (mg/L)	525±35
Selenium (µg/L)	20±5
Sodium (mg/L)	180±40
Zinc (mg/L)[c]	1.2±0.2

[a] Institute of Medicine 1991, unless otherwise indicated. Mature signifies ≥ 21 days postpartum.
[b] Underwood, 1994. Value for well-nourished women is 670 µg/L.
[c] Krebs et al. (1995) have reported zinc concentration in breast milk of 0.93±0.58 and 0.77±0.51mg/L at 6-8 and 9 months of lactation, respectively. We have used Krebs' values for computing the amount of zinc from breast milk.

4.3.2 Protein and micronutrient intakes from breast milk

The amounts of protein and micronutrients provided to the infant in breast milk were calculated using the same approach that was used to estimate energy intakes from breast milk. Thus, the concentration of each nutrient in breast milk was multiplied by our estimates of the amount of breast milk consumed at different ages in developing countries (reported above in section 3.1.1 and Table 7[2]). As before, data were from exclusively breast-fed infants up to 6 months of age and from all infants regardless of mode of feeding (exclusive or partial) after this age.

4.3.3 Effects of maternal nutrient intake and status on breast milk composition

The concentration of nutrients in breast milk is most affected by the mother's intake of water soluble vitamins, and to a lesser extent, by her intake and stores of fat soluble vitamins. In contrast, with few exceptions, neither maternal intake nor stores affect the amount of minerals secreted in breast milk. Where maternal intake can affect the secretion of nutrients into milk, there is usually a plateau above which a further increase in intake will no longer increase the concentration of the nutrient in milk.

For the purposes of predicting risk of infant or maternal micronutrient deficiencies and the potential impact of maternal supplementation on breast milk composition, and for planning appropriate interventions, it is useful to classify micronutrients during lactation into two groups, as shown in Table 23 (Allen, 1994b) and discussed below. Table 24 summarizes the effects of maternal deficiency of specific nutrients on their breast milk content, and on infant nutritional status. In addition, available information on the effect of maternal supplementation on breast milk content and on infant or maternal status is presented.

Table 23. Micronutrient categories based on the effect of maternal intake and status on the micronutrient content of breast milk

Group I Affected by maternal status	Group II Not affected by maternal status
Thiamin	Folic acid
Riboflavin	Vitamin D
Vitamin B_6	Calcium
Vitamin B_{12}	Iron
Vitamin A	Copper
Iodine	Zinc
Selenium	

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[2] Average breast milk intake (g/d) was 674, 616, and 549 at 6-8, 9-11, and 12-23 months respectively. Children receiving "low" amounts of breast milk (mean-2 SD) consumed 372, 272 and 175 g of breast milk daily while the "high" breast milk consumers (mean +2 SD) ingested 976, 960, and 923 g/d at 6-8, 9-11 and 12-23 months respectively (computed from Table 7 for "all" infants in the respective age categories).

Group I

This group includes thiamin, riboflavin, vitamins B_6 and B_{12}, vitamin A, iodine, and selenium. During lactation, maternal intake and stores of these nutrients are of most concern because:

- Low maternal intake or stores reduces the amount of these nutrients secreted in milk
- This affects infant development adversely
- The concentration in breast milk can be rapidly restored by increasing maternal intake
- Infant stores of most of these nutrients are low and readily depleted, increasing the infant's dependence on a consistently adequate supply from breast milk and/or complementary foods.

Maternal deficiency of thiamin rapidly and severely depletes the amount of the vitamin secreted in milk. As a result of this, and low infant stores, infantile beriberi can appear within a few weeks after birth (Institute of Medicine, 1991). Breast-milk thiamin concentrations have been reported in undernourished Indian women (0.11 mg/L increasing to 0.27 mg/L with supplementation, Deodhar, Rajalakshmi & Ramakrishnan, 1964), and Gambian women (0.16 mg/L, increasing to 0.22 mg/L with supplementation, Prentice et al., 1983). Thiamin deficiency used to be common in populations consuming diets based on polished white rice, but fortification programmes are believed to have restricted the common occurrence of this deficiency to locations such as refugee camps.

Similarly, breast-milk riboflavin concentration falls as a result of maternal depletion and low intake. Reported average concentrations were 0.20 mg/L in poorly-nourished Indian women consuming 0.18 mg of riboflavin per day (Deodhar, Rajalakshmi & Ramakrishnan, 1964), and 0.16 mg/L in Gambian women with a daily intake of 0.5 mg riboflavin (Bates et al., 1982a). In the latter study a supplement of 2 mg of riboflavin per day for 12 weeks increased milk concentrations to 0.23 mg/L. Riboflavin deficiency is more common where the intake of animal products is low, and has been reported in central America, China, the former Yugoslavia, and parts of Africa. However, there are no national prevalence data, and there is little information on the extent to which the low observed breast milk concentrations of the vitamin cause riboflavin deficiency in the infant.

The prevalence of vitamin B_6 deficiency in developing countries is unknown. In periurban Egypt, one-third of a group of lactating women had sub-optimal vitamin B_6 status based on low concentrations of B_6 (< 68 µg/L) in breast milk (McCullough et al., 1990). Lower milk vitamin B_6 concentrations were associated with infant and maternal behavioural changes. The mean milk vitamin B_6 concentration was about 84 µg/L. The milk of poor Indian women contained 80 µg/L which increased to 160 µg/L after the usual dietary intake of 0.35 mg/day was supplemented with an additional 40 mg/day (Deodhar, Rajalakshmi & Ramakrishnan, 1964). However, a concentration of 120 µg/L was observed in the breast milk of Gambian women, which was not affected by supplementation (Prentice et al., 1983).

The concentration of vitamin B_{12} in breast milk is also strongly dependent on maternal B_{12} status and is correlated with fasting maternal plasma B_{12} concentration. Because maternal vitamin B_{12} deficiency during pregnancy can reduce foetal storage of the vitamin as well as subsequent secretion of the vitamin in breast milk, this can produce clinical signs of B_{12} deficiency in the infant around 4 months of age (Allen, 1994c). It is virtually impossible to compare values of breast-milk B_{12} concentrations among different countries, because of differences among assays. Women in the United States of America who consume low amounts of vitamin B_{12} because they are strict vegetarians (the vitamin is only found in animal products) produce milk low in vitamin B_{12} (approximately 0.2 µg/L after 2-3 years of becoming a vegan compared to about 0.5 µg/L for recent vegetarians) and this results in biochemical signs of B_{12} deficiency in the infant at 6 months of age (Specker et al., 1990). In the Netherlands, at 2-3 months postpartum women consuming macrobiotic diets had an average breast-milk vitamin B_{12} concentration of 0.36 µg/L, compared to 0.44 µg/L for omnivores (Dagnelie et al., 1992). The prevalence of this vitamin deficiency in developing countries may have been underestimated, especially if it is malabsorbed as a result of parasitic or bacterial infections (Allen et al., 1995).

Due to seasonal variations in maternal intake, ascorbic acid concentrations in breast milk also vary seasonally in some regions. For example, in the Gambia, concentrations were about 25 mg/L in the low intake season compared to over 40 mg/L in the season when ascorbic intakes were higher (Bates et al., 1982b). However, ascorbic acid has not been included as a Group I nutrient because the little information on this question suggests that breast-milk ascorbic acid can easily meet infant requirements even when maternal intake is low (Bates et al., 1982b). Also, milk concentrations increased only slightly when a 35 mg/d supplement was provided to lactating women (Bates et al., 1982b).

There is a wide range in the reported concentrations of retinol in breast milk of women in developing countries, probably due in part to differences in methods used for sampling and analysis. For example, in spite of similar maternal serum retinol concentrations, values for breast-milk retinol at 3-4 months of lactation were reportedly 170, 180, 320, 520 and 640 µg/L in west Java (Muhilal et al., 1988), El Salvador (Arroyave et al., 1974), Bangladesh (Roy et al., 1989), the Gambia (Bates, 1983), and in central Java (Stoltzfus et al., 1993) respectively. When the breast milk concentration of vitamin A falls below 300 µg/L, and especially below 200 µg/L, clinical signs of this vitamin deficiency are more prevalent in breast-fed infants. These signs are rare, even after weaning, where breast-milk vitamin A concentration exceeds 500 µg/L. Vitamin A-deficient mothers may not secrete enough of the vitamin in their milk to build up infant liver stores (which are low at birth even in well-nourished populations) or to protect the infant from deficiency beyond six months of age (Underwood, 1994). For this reason, maternal supplementation with the vitamin during early lactation has been called "a window of opportunity" to improve the vitamin A stores of the infant, and to prevent depletion in their mothers, in developing countries (Underwood, 1994). In addition, complementary foods become very important as a source of vitamin A for children in populations with a high prevalence of vitamin A deficiency.

Lower breast-milk iodine concentrations have been reported in endemic iodine deficiency areas where iodine deficiency is aggravated by high thiocyanate intakes from poorly detoxified cassava (Delange, 1985). There is little information on the iodine content of breast milk in regions where dietary intakes of iodine are low, so that the extent of this problem is unknown; it is possible that in deficiency the mammary gland sequesters enough iodine from maternal plasma to prevent milk levels from falling (Delange, 1985).

Although the concentration of most minerals in breast milk is not affected by maternal diet or status, selenium is an exception to this generalization (Funk et al., 1990). Breast-milk selenium concentration is lower (< 10 µg/L compared to normal values of 10-30 µg/mL) in regions with endemic selenium deficiency because of a low concentration of the mineral in soil, such as China (Levander, Moser & Morris, 1987), Nepal (Moser et al., 1988) and New Zealand (Casey, 1988). It has also been reported to be lower in the breast milk of women with high parity. Virtually nothing is known about the effects of low breast milk concentrations on the selenium status and function of the infant.

Group II

Nutrients in this category include folate, vitamin D, calcium, zinc, iron, and copper. They have the following characteristics:

- Maternal intake (including supplements) and deficiency have relatively little effect on their secretion in breast milk
- milk concentrations are not reduced when the mother is deficient, therefore, she is vulnerable to further depletion during lactation
- Maternal supplementation with these nutrients during lactation is more likely to benefit the mother than her infant
- Poor maternal intake or stores of these nutrients will have little effect on the amounts that infants will require from complementary foods.

Lactation puts heavy demands on maternal folate stores because of the high folate content of breast milk. Folate-deficient women tend to become even more depleted during lactation and breast-milk folate concentrations are maintained at the expense of maternal stores (O'Connor, 1994). Milk folate concentrations do not fall unless the mother is severely depleted.

Breast milk contains 0.3-1.5 µg cholecalciferol (vitamin D) per litre (Specker 1994), which does not come close to providing the approximately 6 µg/d vitamin D required by the breast-fed infant. The infant obtains the remainder of its requirement by synthesizing the vitamin in its skin when exposed to adequate ultraviolet radiation, and from stores accumulated *in utero* (Fraser, 1994). Breast-milk and maternal plasma concentrations of the main storage metabolite, 25-hydroxyvitamin D, are correlated. Specker et al. (1990) observed concentrations around 0.25 µg/L in breast milk from mothers of infants diagnosed with vitamin D deficiency rickets. However, breast milk concentrations of vitamin D do not affect infant vitamin D status unless the mother consumes high amounts of the vitamin (2 000 IU/d or 50μg cholecalciferol) as a supplement.

Although maternal intake has not been shown to affect the secretion of calcium in breast milk, lower milk concentrations have been reported in a Gambian population where the usual maternal intake of calcium is extremely low (Prentice, 1994; Prentice et al., 1995). In the Gambia, at 13 weeks of lactation the concentration was 209 mg/L compared to 260 mg/L in well-nourished residents of the United Kingdom (Prentice et al., 1995). However, racial differences in milk calcium concentration cannot be ruled out. Supplementing the Gambian mothers with calcium did not increase milk calcium concentrations.

While reports on the relationship between maternal zinc status and breast-milk zinc content have been conflicting, there is a general consensus that breast-milk zinc content is not lower in developing countries and is relatively unaffected by zinc intake. Similarly, neither maternal status nor her dietary intake of zinc or copper (including supplements) has any effect on the secretion of these nutrients in breast milk (Institute of Medicine, 1991).

4.3.4 Implications of differences in breast milk composition between developed and developing countries

In the following sections of this report we will base our estimates of the amounts of micronutrients needed in complementary foods on the breast milk composition data shown in Table 22, i.e. from data on women in industrialized countries. The only exception to this is vitamin A, for which we have recent estimates of the concentration in breast milk of women in developing countries (Underwood, 1994). The rationale for using values from well-nourished women for the other nutrients is as follows. First, for most nutrients there were very few data on their concentration in breast milk in developing countries. Second, even when there were such data, there were usually no comparable data presented on well-nourished women in the same settings, or collected by the same investigators. This is important because without careful attention to the method of milk collection and analysis, and the exact stage of lactation, such comparisons can lead to erroneous conclusions about the extent of differences in milk composition. Finally, as will become evident in the subsequent sections of the report, complementary foods are probably more inadequate in terms of their mineral density than in their content of vitamins, yet maternal malnutrition is most likely to reduce the content of the latter in milk.

For these reasons we have estimated the desired nutrient intake from complementary foods, or the desired nutrient density of complementary foods, based on the breast milk content of Group I nutrients for women in industrialized countries (except for vitamin A). This means that where maternal dietary patterns are likely to cause deficiencies of Group I nutrients in breast milk, including regions of endemic iodine or selenium deficiency, particular attention will need to be paid to the question of whether the density of these nutrients in complementary foods is adequate to meet infant requirements. For this purpose, the general approach to estimating the required nutrient density of complementary foods can be modified by using the lower estimates of the relevant nutrient concentrations in breast milk presented in Table 24. Alternatively, if breast milk composition data exist for a particular population group, these should be used. The steps to be followed are described in section 4.5.1. To estimate the amount of nutrient needed from complementary foods, for each age group one should calculate the amount of the nutrient supplied by breast milk (nutrient concentration multiplied by the appropriate breast milk volume in Table 7), and subtract this value from the recommended nutrient intake (Table 25). To calculate the desired nutrient density in complementary foods (per 100 $kcal_{th}$), one should divide the amount of nutrient needed (previous calculation) by the energy needed from these foods (Table 10) and multiply by 100.

The decision about which specific nutrients are of special concern is discussed further in section 4.5.3, in the context of whether or not it is difficult to supply adequate amounts in typical complementary foods.

4.4 Recommended protein and micronutrient intakes for infants and young children

After an extensive review of available information, the decision was made to use the British Daily Reference Values (Department of Health, 1991) for most of the nutrient requirements of infants and young children (Table 25). They comprise the most recent and complete compilation of nutrient requirements and include values for the Estimated Average Requirement (EAR) as well as the Recommended Nutrient Intake (RNI) which is the EAR plus a safety factor of +2 SDs, equivalent to the Recommended Dietary Allowances in the United States of America.

The bases of derivation of the British RNIs for infants were examined to determine if they were reasonable for present purposes, and if they could be improved. For most nutrients the RNIs for infants are based on the amount of the nutrient consumed in breast milk, adjusted for estimated absorption and utilization, whereas for others the requirements are based on levels known to prevent deficiencies or are calculated using a factorial approach. The requirements for thiamin and riboflavin were recalculated based on the most recent estimates of energy recommendations for these age-groups (discussed in section 3.2.1, Table 9), but because the estimates were quite similar to the RNIs, the RNIs were retained. For protein, folate, iron and zinc the decision was made to estimate requirements using other sources that were more recent and complete. Protein requirements were recalculated based on a recent compilation of protein requirements for infants and children (Dewey et al., 1996b), prepared for the International Dietary Energy Consultative Group. For iron and folate the FAO/WHO recommendations (1988) were used because they list intakes for iron at three levels of iron bioavailability (low, intermediate, and high) and provide precise age-specific recommendations for folate. Table 25 includes estimated recommendations for iron based on a diet with the three levels of iron bioavailability. Zinc requirements were calculated using a factorial approach based on new estimates for infants (Krebs & Hambidge, 1986; Krebs et al., 1993) and then extrapolated to older children. It was

Table 24: The influence of maternal micronutrient deficiencies and supplements during lactation on breast milk and infant micronutrient status

Nutrient deficiency	Effect of maternal deficiency on milk content	Effect of maternal deficiency on infant	Effect of maternal supplementation on milk content	Effect of maternal supplementation on infant	Author, year
Vitamins					
Thiamin	⇓ to 0.11mg/L	beriberi	⇑ to normal	⇓ infant beriberi	Prentice et al. 1983 Deodhar, Rajalakshmi & Ramakrishnan, 1964 Institute of Medicine, 1991
Riboflavin	⇓ to 0.2 mg/L	high EGRAC[a]	⇑	⇓ maternal & infant EGRAC	Deodhar, Rajalakshmi & Ramakrishnan, 1964. Bates et al., 1982a
Vitamin B_6	⇓ to 90 μg/L	neurological problems	⇑	⇓ neurological problems	McCullough et al. 1990
Folate	**[b]	unknown	**	none, but ⇑ maternal status	Thanangkul et al. 1994
Vitamin B_{12}	⇓ to <0.5 μg/L	increased urine MMA[c] neurological problems developmental delays	⇑	⇓ infant's plasma MMA	Specker et al. 1990 Allen, 1994c
Ascorbic acid	⇓ to 25 mg/L	unknown	⇑ (small)	unknown	Bates et al., 1982b
Vitamin A	⇓ to 170-500 μgRE/L	low serum retinol	⇑	⇑ serum retinol for months after single oral dose. ⇑ infant stores	Muhilal et al, 1988 Stoltzfus et al., 1993 Underwood, 1994
Vitamin D	⇓ to 0.25 μg/L	⇑ risk rickets, but depends more on sunshine exposure	⇑	⇑ serum 25 (OH)D if dose >2,000 IU/day	Specker, 1994

[a] erythrocyte glutathione reductase activity coefficient
[b] no change
[c] methylmalonic acid

Nutrient deficiency	Effect of maternal deficiency on milk content	Effect of maternal deficiency on infant	Effect of maternal supplementation on milk content	Effect of maternal supplementation on infant	Author, year
Minerals					
Calcium	⇓ to 210 mg/L	⇓ bone mineral, but relative in utero vs postpartum influence unclear	**	none	Fraser, 1994 Prentice, 1994 Prentice et al., 1995
Iron	**		**	none	Institute of Medicine, 1992
Zinc	**		**	none	Institute of Medicine, 1992
Copper	**			none	Institute of Medicine, 1992
Iodine	**/⇓	uncertain because impact of in utero deficiency more important	⇑	unknown	Delange, 1995
Selenium	⇓ to $\leq 10\ \mu g/L$	⇓ plasma and RBC Se	⇑	unknown	Levander, Moser & Morris, 1987 Moser et al., 1988 Casey 1988 Funk et al., 1990

Table 25. Nutrient requirements during first 2 years of life[a]

Nutrient	Recommended Nutrient Intake[b]					SNI[c]
	0-2	3-5	6-8	9-11	12-23	
Protein (g/d)[d]	9.6	8.5	9.1	9.6	10.9	
Vitamins						
Vitamin A (μg RE/d)[e]	350	350	350	350	400	
Biotin (μg/d)						10-200
Folate (μg/d)[f]	16	24	32	32	50	
Niacin (mg/d)	3	3	4	5	8	
Pantothenic acid (mg/d)						1.7
Riboflavin (mg/d)	0.4	0.4	0.4	0.4	0.6	
Thiamin (mg/d)	0.2	0.2	0.2	0.3	0.5	
Vitamin B_6 (mg/d)	0.2	0.2	0.3	0.4	0.7	
Vitamin B_{12} (μg/d)	0.3	0.3	0.4	0.4	0.5	
Vitamin C (mg/d)	25	25	25	25	30	
Vitamin D (μg/d)	8.5	8.5	7	7	7	
Vitamin E (mg/g PUFA)						0.4
Vitamin K (μg/d)						10
Minerals						
Calcium (mg/d)	525	525	525	525	350	
Chloride (mg/d)	320	400	500	500	800	
Copper (mg/d)	0.2	0.3	0.3	0.3	0.4	
Fluoride (mg/d)[g]						0.05
Iodine (μg/d)	50	60	60	60	70	
Iron (mg/d: Low bioav[h]	---	21	21	21	12	
Med bioav[h]	---	11	11	11	6	
High bioav[h]	---	7	7	7	4	
Magnesium (mg/d)	55	60	75	80	85	
Manganese (μg/d)						16
Phosphorus (mg/d)	400	400	400	400	270	
Potassium (mg/d)	800	850	700	700	800	
Selenium (μg/d)	10	13	10	10	15	
Sodium (mg/d)	210	280	320	350	500	
Zinc (mg/d)	4.0	4.0	5.0	5.0	6.5	
	---	2.8[i]	2.8[i]	2.8[i]	2.8[i]	

[a] Dietary Reference Values for energy and nutrients for the United Kingdom (Dept of Health 1991), unless otherwise indicated.

[b] RNI = estimated average requirement plus a safety factor of 2 SD.

[c] Safe nutrient intake from British Dietary Reference Values. This indicates "intake or range of intakes for a nutrient where there is not enough information to estimate the requirements. The SNI is an amount that is enough for almost everyone but not so large as to cause undesirable effects."

[d] Dewey et al., 1996b. These estimates for protein requirements are not adjusted for digestibility or protein quality and were derived using median weight for age estimates from the NCHS: 4.6, 6.7, 8.3, 9.4 , and 11.2 kg for 0-2, 3-5, 6-8, 9-11, and 12-23 months of age.

[e] μg Retinol Equivalents /d.

[f] FAO/WHO, 1988.

[g] Fluoride requirements based on the SNI level of 0.05 mg/kg/d using body weights from NCHS mentioned above (see footnote c).

[h] Based on FAO/WHO, 1988 estimates for basal requirement including variability, and assuming iron bioavailability as low (5%), intermediate (10%), or high (15%). Basal Requirement is the amount needed to prevent clinically demonstrable impairment of function. It is sufficient to meet growth and reproduction. However, reserves in the tissue will be low or non-existent and susceptible to problems caused by short-term inadequacies.

[i] Based on estimated losses and allowance for growth (See Annex III).

assumed that endogenous losses in 12-23-month-old children are 50% higher than in the first year of life. Based on estimated zinc losses (Krebs et al., 1993) and an allowance for growth (Fomon et al., 1982) the need for zinc is 0.7 mg/d. Assuming 30% absorption and a SD of 11% (as used to develop the RNI) the estimated recommended intake for zinc is 2.8 mg (Annex III). New recommendations for zinc intakes were published by WHO in 1996 (WHO, 1996b). For the 6-12 month age period these are 2.2-3.3, 3.4-5.6, and 8.0-11.1 mg/d for diets with high, moderate and low availability respectively. For the 1-2-year-old period the values are 2.1-3.3 (high), 3.4-5.5 (moderate) and 7.9-12.0 (low bioavailability). Thus the estimates in Table 25 are equivalent to WHO's recommendations for a high bioavailability diet, and would need to be about three times higher for a low bioavailability diet.

In general, protein and vitamin requirements increase by about 10-50% from early infancy through 2 years of age (Table 25). However, this is not true for some nutrients (including iron and calcium) that are deposited in large amounts during growth. For such nutrients there is relatively little change in requirements; although body weight increases with age, the rate of growth decreases, especially in the second year.

Amino acid requirements have not been considered here for the following reasons. First, there is considerable debate about the requirements (Dewey et al., 1996b) and estimates vary by a factor of 2 or 3 for some essential amino acids based on the method used to estimate requirements (Young, Bier & Pellett, 1989). Second, as will be apparent in the following sections of this report, unless fortification of complementary foods occurs, substantial amounts of animal products would be needed to meet some of the micronutrient requirements of infants and young children; because animal proteins are of high biological value this would satisfy amino acid requirements. However, we recognize that it may not be feasible to increase animal product intake in some situations. Third, as discussed above, it is probable that protein intake from complementary foods is more than adequate in most situations. This means that the intake of most amino acids will also be adequate if the protein quality of the overall diet is reasonable.

4.5 Providing protein and micronutrients in complementary foods

4.5.1. Age-specific estimates of amounts of protein and micronutrients required from complementary foods

Similar to the calculations of the amount of energy needed from complementary foods, the approach we used for protein and micronutrients was to multiply the amounts of these nutrients provided by breast milk, as described in Table 22, by the volume of breast milk consumed by infants in developing countries (Table 7), and subtract these values from the recommended nutrient intakes (Table 25) for infants and young children. The differences, shown in Table 26, represent the amounts of nutrients that must be provided by complementary foods to meet the nutrient demands of infants and children with "low", "average" and "high" breast-milk consumption at different ages. In Table 27 these values are expressed as the desired nutrient density of complementary foods (i.e. amount per 100 kcal_{th} of food) based on our estimates of the quantity of energy that must be supplied by these foods to meet energy requirements (Table 10).

Table 26. Estimated nutrient needs from complementary foods by level of usual breast milk intake[a]

Nutrient	6-8 months			9-11 months			12-23 months		
	Breast-milk intake			Breast-milk intake			Breast-milk intake		
	Low	Avg	High	Low	Avg	High	Low	Avg	High
Protein (g/d)	5.2	2	0	6.7	3.1	0	9.1	5	1.2
Vitamin A (μgRE/d)	164	13	0	214	42	0	313	126	0
Folate (μg/d)	0	0	0	9	0	0	35	3	0
Niacin (mg/d)	3	3	3	5	4	4	8	7	7
Pantothenic acid (mg/d)	1.0	0.5	0	1.2	0.6	0	1.4	0.7	0
Riboflavin (mg/d)	0.3	0.2	0.1	0.3	0.2	0.1	0.5	0.4	0.3
Thiamin (mg/d)	0.1	0.1	0	0.2	0.2	0.1	0.5	0.4	0.3
Vitamin B_6 (mg/d)	0	0	0	0	0	0	0	0	0
Vitamin B_{12} (μg/d)	0	0	0	0.1	0	0	0.3	0	0
Vitamin C (mg/d)	10	0	0	14	0	0	23	8	0
Vitamin D (μg/d)	6.8	6.6	6.5	6.9	6.7	6.5	7	6.7	6.4
Vitamin K (μg/d)	9.2	9	8	9.4	9	8	9.6	9	8
Calcium (mg/d)	421	336	252	449	353	256	301	196	92
Chloride (mg/d)	344	217	90	386	241	97	727	569	412
Copper (mg/d)	0.2	0.1	0.1	0.2	0.1	0.1	0.4	0.3	0.2
Fluoride (μg/d)	0	0	0	0	0	0	0	0	0
Iodine (μg/d)	19	0	0	30	0	0	51	10	0
Iron (mg/d): Low bioav	20.9	20.8	20.7	20.9	20.8	20.7	11.9	11.8	11.7
Med bioav	10.9	10.8	10.7	10.9	10.8	10.7	5.9	5.8	5.7
High bioav	6.9	6.8	6.7	6.9	6.8	6.7	3.9	3.8	3.7
Magnesium (mg/d)	62	51	41	70	58	46	79	66	53
Manganese (μg/d)	14	12	10	14	12	10	15	13	10
Phosphorus (mg/d)	348	306	263	362	314	266	246	193	141
Potassium (mg/d)	505	346	188	557	377	196	708	512	315
Selenium (μg/d)	3	0	0	5	0	0	11	4	0
Sodium (mg/d)	253	199	144	301	239	177	469	401	334
Zinc (mg/d)[b]	4.6	4.2	3.8	4.7	4.3	3.8	6.3	5.8	5.4
Zinc (mg/d)[c]	2.5	2.2	1.9	2.6	2.3	2.1	2.7	2.4	2.1

[a] The categories Low, Avg, and High correspond to breast-milk intake (g/d) being mean -2SD, mean and mean +2SD.

[b,c] Zinc needs from complementary foods have been estimated in 2 ways indicated by superscripts b, and c respectively as follows:

[b] Based on amount of zinc in breast milk from Institute of Medicine (1991) and zinc requirement from British DRV (Department of Health, 1991)

[c] Based on amount of zinc in breast milk from Krebs et al. (1995) and estimated zinc requirements using data from Krebs & Hambidge (1986) and Krebs et al. (1993) (See Annex III)

Table 27. Desired nutrient density of complementary foods (per 100 kcal$_{th}$) by level of usual breast-milk intake[a]

	6-8 months			9-11 months			12-23 months		
Nutrient	**Breast-milk intake**			**Breast-milk intake**			**Breast-milk intake**		
	Low	**Avg**	**High**	**Low**	**Avg**	**High**	**Low**	**Avg**	**High**
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
Pantothenic acid (mg)	0.2	0.2	0	0.2	0.1	0	0.1	0.1	0
Riboflavin (mg)	0.06	0.07	0.14	0.04	0.04	0.04	0.05	0.05	0.06
Thiamin (mg)	0.02	0.04	0	0.03	0.04	0.04	0.05	0.05	0.06
Vitamin B$_6$ (mg)	0	0	0	0	0	0	0	0	0
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	1.1	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
Chloride (mg)	74	81	123	57	53	42	73	76	84
Copper (mg)	0.04	0.04	0.14	0.03	0.02	0.04	0.04	0.04	0.04
Fluoride (µg)	0	0	0	0	0	0	0	0	0
Iodine (µg)	4	0	0	4	0	0	5	1	0
Iron (mg):Low bioav	4.5	7.7	28.3	3.1	4.6	9.0	1.2	1.6	2.4
Med bioav	2.3	4	14.7	1.6	2.4	4.7	0.6	0.8	1.2
High bioav	1.5	2.5	9.2	1	1.5	2.9	0.4	0.5	0.8
Magnesium (mg)	13	19	56	10	13	20	8	9	11
Manganese (µg)	3	4	14	2	3	4	1	2	2
Phosphorus (mg)	75	114	360	54	70	116	25	26	29
Potassium (mg)	109	129	258	83	84	86	71	69	64
Selenium (µg)	0.6	0	0	0.7	0	0	1.1	0.5	0
Sodium (mg)	54	74	197	45	53	77	47	54	68
Zinc (mg)[b]	1	1.6	5.2	0.7	1	1.7	0.6	0.8	1.1
Zinc (mg)[c]	0.5	0.8	2.6	0.4	0.5	0.9	0.3	0.3	0.4

[a] The categories Low, Avg, and High correspond to breast-milk intake being mean -2SD, mean and mean +2SD. Nutrient density for each category has been computed using the caloric density of complementary foods for each age group from Table 4.

[b,c] Zinc density from complementary foods is based on energy needed from complementary foods from Table 4 and estimated 2 different ways indicated by superscripts b, and c respectively as follows:

[b] Based on amount of zinc in breast milk from Institute of Medicine (1991) and zinc requirement from British DRV (Department of Health, 1991)

[c] Based on amount of zinc in breast milk from Krebs et al. (1995) and estimated zinc requirements using data from Krebs & Hambidge (1986) and Krebs et al. (1993) (See Annex III)

When expressed as an approximate percentage of total daily requirements, and assuming an average intake of breast milk, across age groups complementary foods need to provide 5-30% of the vitamin A, 20-45% of the protein, 50-80% of the thiamin, 50-65% of the riboflavin, 60% of the calcium, 85% of the zinc, and almost 100% of the iron. The lower the concentration of the nutrient in breast milk, the more will be needed from complementary foods. The estimates suggest that almost no vitamin B_6, B_{12}, vitamin C or folate would be needed from complementary foods because breast milk has a high content of these nutrients. The exception would be for vitamins B_6 and B_{12} when the mother is depleted in these nutrients.

4.5.2 Nutrient density and bioavailability

The quantity of nutrients available for infant growth and development depends on the amounts in breast milk and in complementary foods, and the bioavailability of these nutrients. Bioavailability is a term usually used to describe the "absorbability" of nutrients, although it more precisely refers to both the absorbability and the availability to be utilized for metabolic purposes. For most nutrients, bioavailability is measured either by disappearance of isotopically-labelled nutrients from the intestine, or in balance studies evaluating the difference between intake and appearance in the faeces. Bioavailability actually reflects absorption when these methods are used. In the case of iron, bioavailability is usually assessed by mixing and consuming isotopically-labelled iron with the food and measuring the amount of labelled iron incorporated into red blood cells 2 weeks later. With this method, bioavailability reflects both absorption and utilization of the label for erythrocyte synthesis.

There are major differences between animal products and plant-derived foods in terms of both the density of micronutrients (amount/100 $kcal_{th}$), and their bioavailability. Per 100 $kcal_{th}$, animal products usually contain more of certain nutrients such as retinol, vitamins D and E, riboflavin, vitamin $B_{12,}$ calcium, and zinc. The iron content of some animal products is high (e.g. meat, fish and poultry) whereas in others it is low (milk and dairy products). In contrast, the density of thiamin, vitamin B_6, folic acid, and ascorbic acid is generally higher in plants. Some plants, such as legumes and maize, also contain substantial amounts of minerals such as iron but the bioavailability of minerals from plant products generally is poor.

Micronutrients that have poor bioavailability when consumed in plant products include iron, zinc, calcium, and ß-carotene in leafy and some other vegetables. In addition, the absorption of ß-carotene, retinol and other fat soluble vitamins is impaired when diets are low in fat (de Pee et al., 1995).

About 40% of the iron in animal products is in the form of haem. The bioavailability of haem iron is around 25%, compared to 2-8% from non-haem sources. This difference is explained by the fact that the haem molecule is absorbed intact, and its uptake into mucosal cells is unaffected by the presence of other food constituents (except calcium) in the intestine. Meat, poultry and fish also contain an unidentified "meat factor" that improves the absorption of non-haem iron from foods.

The bioavailability of iron, zinc and calcium is severely reduced in cereals and legumes that have a high content of phytic acid. Phytates are large molecules that constitute about 1-2% of the weight of many cereals, nuts and legumes. In plants they are usually complexed with essential minerals, and the complexes are insoluble and unavailable for absorption under normal physiological conditions. The high phytate content of most plant staples is the primary cause of poor iron, zinc and calcium absorption from plant-based diets. In addition, uronic acids found in the fibre of fruits and vegetables can inhibit the absorption of calcium. The inhibitory effect of phytate on iron absorption can be substantially alleviated if ascorbic acid is consumed at the same meal. For example, consuming foods or a supplement containing 25 mg of ascorbic acid will approximately double the amount of iron absorbed from cereals such as maize, wheat and rice (Allen & Ahluwalia, 1997). However, ascorbic acid does not improve zinc or calcium absorption from plants. The phytate content can be substantially reduced by fermentation (Brune et al., 1992), germination (Svanberg & Sandberg, 1987) and soaking (Sandberg & Svanberg, 1991). These may be practical approaches to increasing the bioavailability of minerals, including iron and zinc, from complementary foods, especially in areas where these methods of food preparation are familiar.

One feature of Tables 25 and 26 is separate recommendations for the amount of iron required from diets with "low", "intermediate", or "high" bioavailability. This categorization follows FAO/WHO's model of grouping single meals (or diets) in these three bioavailability categories (FAO/WHO, 1988). The absorption of non-haem iron from these meals is assumed to be 5, 10 and 15% respectively for an individual with no iron stores. A low bioavailability meal (or diet) is defined as being monotonous, and consisting of cereals (especially maize, whole wheat flour and sorghum which strongly inhibit iron absorption), legumes, roots and/or tubers and negligible quantities of meat, fish, or ascorbic acid-rich foods. An intermediate bioavailability diet consists mainly of other cereals, roots and/or tubers and negligible quantities of ascorbic acid or animal products. A low bioavailability diet can be improved to moderate bioavailability by consuming more ascorbic acid-rich foods, meat or fish. A high bioavailability diet is diversified and contains generous amounts of meat, fish, poultry and/or foods rich in ascorbic acid. This diet more closely resembles that of wealthier population groups in developing countries and of most segments of populations in industrialized countries. However, the iron bioavailability from complementary foods given to many infants and young children in developing countries is likely to be predominantly low or intermediate.

Coffee and tea have strong inhibitory effects on iron absorption. In some countries, such as Guatemala, it is common to feed infants coffee. In others, such as Egypt, infants are given teas from an early age. Advice should be given to discontinue the feeding of coffee or tea to infants because of the inhibitory effects of these beverages on iron absorption from foods consumed in the same meal, or from iron supplements (Dewey et al., 1997b). However, this may not be appropriate where these drinks are a major source of milk for the infant. Research is needed on the impact of such recommendations across locations where different types of tea or coffee drinks are given to infants and young children.

The absorption of fat soluble vitamins is impaired by a low dietary fat content. The diets of infants in many developing countries are low in fat, especially where animal products provide little of the dietary energy. Consumption of some breast milk would presumably increase the absorption of carotene and retinol from these foods, if eaten at more or less the same time.

4.5.3 Defining the problem nutrients

In this section we examine food intake data from breast-fed infants aged 6-8 months and 9-11 months in Peru and the United States of America, and from preschoolers aged from 18 to 24 months in rural Mexico. We recognise that the types and amounts of the complementary foods consumed by the children in these three studies are not representative of those consumed in many regions of the world. Nevertheless, the data can validly be used to:

- Illustrate a systematic approach that can be replicated in other population groups to evaluate the nutritional adequacy of complementary foods for infants of different ages
- Obtain estimates of the largest portion size of specific foods consumed by these children in each age group
- Compare the nutrient densities of specific foods to the nutrient requirements of the infants.

"Problem nutrients" are defined here as those for which there is most discrepancy between their content in complementary foods and the amount required by the infant. They were determined in the current analyses by comparing the estimates of desirable nutrient density of complementary foods (Table 27) with the actual densities of these nutrients in the diets of children in Huascar, Peru, and in Davis, California (for ages 6-8 and 9-11 months) and in Solis, Mexico (for ages 12-24 months). Details of the populations and food intake methods are described elsewhere for the data from Peru (Lopez de Romaña et al., 1989; Creed de Kanashiro et al., 1990), the United States (Heinig et al., 1993a) and Mexico (Allen et al., 1992). The food intake data were converted to nutrients using modified Peruvian food composition tables for Peru, the Food Processor program for the United States, and the WorldFood Dietary Assessment System for Mexico (Bunch & Murphy, 1994). The WorldFood data base contains information on 48 nutrients and other components in 1 800 foods consumed in six countries, including Mexico. It is based on food composition data from multiple sources including the United States Department of Agriculture data bank and tables from other nations.

Table 28 shows the average desired density (i.e. assuming an average breast-milk intake) of selected nutrients compared to the mean, median, minimum and maximum densities reported in the daily intake of infants age 6-8 and 9-11 months in Peru and California.

Table 29 provides the same information for the rural Mexican preschoolers aged 18-24 months. We did not have access to an equivalent data base from the United States for children in the same age range.

Table 28. Nutrient densities (per 100 kcal$_{th}$) of diets consumed by infants in Peru and the United States, 6-11 months

		6-8 months, Peru				**6-8 months, United States**			
	Average desired	**Mean**	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
Protein (g)	0.7	3.2	2.7	0	14.6	2.6	2.3	0.9	6.4
Vitamin A (μgRE)	5	63.0	34.2	0	2210.0	187	65.2	0.3	1583.7
Calcium (mg)	125	83.7	21.0	0.9	184.6	73	59.0	7.6	233.1
Iron (mg)	4[a]	0.4	0.4	0	6.1	3.5	2.7	0.28	11.0
Zinc (mg)	0.8[b]	0.4	0.4	0	2.3	0.4	0.4	0.1	1.0
Riboflavin (mg)	0.07	0.2	0.08	0.08	1.8	0.2	0.2	0.03	0.45
Thiamin (mg)	0.04	0.3	0.04	0	0.15	0.14	0.11	0.03	0.38
Niacin (mg)[c]	1.1	0.49	0.47	0	8.0	1.5	1.4	0.22	3.84
		9-11 months, Peru				**9-11 months, United States**			
	Average desired	**Mean**	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
Protein (g)	0.7	3.0	2.7	0	7.5	3.3	3.1	0.4	6.8
Vitamin A (μgRE)	9	50.8	29.3	0	954	161	61.8	7.47	537.9
Calcium (mg)	78	64.7	26.5	0.3	187.5	56	53.1	14.1	193.1
Iron (mg)	2.4[a]	0.4	0.4	0	3.8	1.9	1.4	0.37	6.1
Zinc (mg)	0.5[b]	0.4	0.4	0	1.2	0.4	0.4	0.14	0.9
Riboflavin (mg)	0.04	0.2	0.08	0	0.8	0.13	0.12	0.05	0.3
Thiamin (mg)	0.04	0.03	0.04	0	0.17	0.11	0.10	0.04	0.29
Niacin (mg)[c]	0.9	0.50	0.46	0	3.9	1.3	1.1	0.34	2.97

[a] Assuming intermediate bioavailability of iron

[b] Based on estimated losses and allowance for growth, as per Table 25.

[c] Excluding the contribution of dietary tryptophan to niacin synthesis (see section 4.5.3).

Table 29. Nutrient densities (per 100 kcal$_{th}$) of diets consumed by preschool children in Mexico, 18-24 months

	Observed nutrient densities Children 18-24 months, Mexico				
	Average desired	**Mean**	**Median**	**Min**	**Max**
Protein (g)	0.7	3.0	2.9	2.3	4.0
Vitamin A (μgRE)	17	30.6	21.7	7.5	180.4
Calcium (mg)	26	56.2	55.9	37.7	78.4
Iron (mg)	0.8[a]	0.6	0.6	0.3	0.9
Zinc (mg)	0.3[b]	0.4	0.4	0.3	0.5
Riboflavin (mg)	0.05	0.05	0.05	0.03	0.1
Thiamin (mg)	0.05	0.05	0.05	0.04	0.06
Niacin (mg)[c]	0.09	0.6	0.6	0.3	0.8

[a] Assuming intermediate bioavailability of iron.

[b] Based on estimated losses and allowance for growth, as per Table 25.

[c] Excluding the contribution of dietary tryptophan to niacin synthesis (see section 4.5.3).

It is apparent that the mean and median densities of protein and vitamin A in complementary foods exceeded the desirable density in all three age groups and locations. On average children in these communities should be able to meet their required intakes of these nutrients from complementary foods, assuming that the vitamin A is highly bioavailable. The 6-8 and 9-11 month age groups consumed diets with a considerably lower calcium density than desirable. Calcium density was adequate in the 12-24-month-old Mexican group, largely because of the high calcium content of *tortillas* (the maize is soaked in lime). However, the bioavailability of this calcium may be poor (Rosado et al., 1992). The iron density of complementary foods, assuming the iron bioavailability was intermediate, was far less than needed by the two younger groups in Peru, but close to the desired density in the older Mexican group. Zinc densities were very low for the youngest age group in Peru and probably inadequate for the older children, given that the bioavailability of the dietary zinc was likely to be poor. Median riboflavin densities were adequate in all groups. Median thiamin densities were just adequate in Peru and Mexico. Niacin densities were low at all ages except in the United States, but these estimates do not take into account the contribution of tryptophan to meeting the need for niacin; 60 mg of tryptophan (contained in about 5 g of protein) is assumed to be equivalent to 1 mg of niacin (National Research Council, 1989).

A comparison of the diets of Peru and Mexico with the diets of United States children revealed interesting similarities and differences. The median vitamin A density of the United States diet was about twice as high as that of Peruvian infants at both 6-8 and 9-11 months. The greatest difference was the higher median iron density of the foods consumed by United States infants - about 7 times higher at 6-8 months and 3.5 times higher at 9-11 months. This was accounted for primarily by the consumption of iron-fortified infant foods in the United States. Interestingly, zinc density was very similar in diets from Peru, Mexico, and the United States, although zinc bioavailability is likely to be superior in the United States because of higher intakes of animal products.

Based on these data, iron, zinc, and calcium were defined as the most important "problem nutrients" because it appeared that the density of these nutrients in complementary foods was substantially less than desired. In addition, although the vitamin A density was adequate, this was also considered to be a "problem nutrient" because of the high prevalence of deficiency in young children in other countries. Presumably children at greatest risk of vitamin A deficiency are those with the lowest intakes of breast milk and/or those whose mothers secrete a lower concentration of the vitamin in their breast milk as a result of inadequate vitamin A intakes and stores. Riboflavin could also be a problem nutrient depending on the degree of reliance on cereals. We examined the riboflavin density of selected cereals, fruits, vegetables and animal products and compared this to the desired density of 0.04 mg/100 kcal_{th} for children aged 9-11 months. The density was about 50% of the desirable value in all cereals, but fruits, vegetables and meats contained at least twice the desirable density and in many cases much more (e.g. 2-3 times more for beans, potatoes, oranges, bananas, eggs and chicken, 4-7 times more for papaya, tomatoes and cheese, and almost 50 times more for chicken liver).

4.5.4 Feasibility of obtaining adequate amounts of problem nutrients from complementary foods

Using the WorldFood Dietary Assessment System, we examined the density (amount per 100 kcal_{th}) of iron, zinc, calcium and vitamin A in the foods consumed in Peru and Mexico. We then calculated the grams of each food that would need to be consumed if that food alone were to meet the nutrient requirements from complementary foods of infants consuming average amounts of breast milk, in each age group. The energy content of these amounts was also calculated. The final step was to make the generous assumption that each of the selected foods could supply up to two-thirds of the total amount of energy required from complementary foods. This is defined as the "energy limit". Tables 30 to 33 provide, for the four nutrients, estimates of the energy limit at each age, the amount of the nutrient required in complementary foods, and the amount that could be obtained from "candidate foods". Candidate foods are all those that can supply the required amount of nutrient in less than the energy limit (i.e. in less than 180 kcal_{th} at 6-8 months, less than 300 kcal_{th} at 9-11 months, and less than 500 kcal_{th} at 12-23 months). Also listed on this table, as "max g", is the maximum amount of each of the candidate foods that was ever reported as consumed in a day by any child in each age group.

Table 30 illustrates the fact that only three foods in Peru had an iron density that could meet the infant's iron requirement from complementary foods, assuming that no more than two-thirds of the children's daily energy intake could be from a single food. These candidate iron foods were all liver (beef, pork and chicken), but only chicken liver was reported as consumed at 6-8 months. Moreover the intake of chicken liver would need to be about three times higher than the maximum of 36 g recorded for a 6-8-month-old infant, and about twice the maximum intake of a 9-11-month-old infant. Seven animal products emerged as candidate iron foods for 12-23-month-old Mexican children, but with the exception of beef and pork liver, no child ever came close to consuming the necessary quantities. Beans, if eaten in twice the quantity ever recorded for the Mexican children, could supply adequate amounts of iron with the caveat that they must be eaten with an ascorbic acid-rich food or meat, fish, or poultry for their iron bioavailability to be categorized as "intermediate".

Table 30. Amounts of iron-rich foods needed to meet the iron requirements of children from complementary foods, by age group and assumed level of iron bioavailability

	Age (months)								
	6-8			9-11			12-23		
A. High bioavailability									
kcal$_{th}$ limit[a]	180			300			500		
Required iron in complementary foods (mg/d)	6.8			6.8			3.8		
Candidate iron foods[b]									
	g	**kcal$_{th}$**	**max g**[c]	**g**	**kcal$_{th}$**	**max g**	**g**	**kcal$_{th}$**	**max g**
Beef liver	136	162	--	136	162	12	76	90	73
Pork liver	155	162	--	155	162	--	86	91	76
Chicken liver	108	125	36	108	125	60	60	70	15
Egg							317	491	65
Fish, sardines							158	306	110
Fish, carp							292	380	96
Beef, lean							253	319	103
B. Average bioavailability									
kcal$_{th}$ limit[a]	180			300			500		
Required iron in complementary foods (mg)	10.8			10.8			5.8		
Candidate iron foods									
Beans	>kcal$_{th}$ limit			>kcal$_{th}$ limit			200	254	125

[a] Kcal$_{th}$ limit = 2/3 of total average energy required from complementary foods at each age.
[b] Candidate foods are all those that contain the required amount of nutrient in ≤ the kcal$_{th}$ limit.
[c] Max = maximum g of that food per day ever consumed by a child in Peru (6-11 mo) or Mexico (12-23 mo)

Five foods, of which three are again liver, are candidate zinc sources for 6-8-month-old infants, while 13 foods could be adequate in zinc for 9-11-month-old infants (Table 31). However, as was the case for iron, the amount of each food that would need to be consumed exceeded the maximum intake recorded, except for dry milk powder at 9-11 months. The older age group in Mexico had 17 candidate zinc foods. Of these, beef and pork liver, lean beef and pork, sardines (canned), and dry milk powder could be consumed in large enough amounts, based on our criterion that the food could supply as much as two-thirds of the total energy needed from complementary foods. The zinc bioavailability from these sources would be high, with the possible exception of dry milk powder.

Table 31. Amounts of zinc-rich foods needed to meet zinc requirements from complementary foods, by age group

	Age (months)								
	6-8			9-11			12-23		
$kcal_{th}$ limit [a]	180			300			500		
Required zinc in complementary foods (mg/d)	2.2			2.3			2.4		
Candidate zinc foods [b]									
	g	$kcal_{th}$	max g [c]	g	$kcal_{th}$	max g	g	$kcal_{th}$	max g
Beef liver	49	58	--	51	61	12	53	63	72
Pork liver	55	58	--	58	60	--	60	63	76
Chicken liver	69	80	36	72	83	60	75	87	15
Fish, dried	42	142	1	44	148	--	46	155	0
Beef, lean	61	77	7	64	81	25	67	84	103
Cheese, fresh				177	244	3	185	255	121
Fish, sardines				100	193	--	104	201	110
Oats				74	285	56	77	297	20
Milk, powder				55	202	98	57	210	96
Fish, carp				153	199	86	160	208	96
Pork w/bone				121	269	--	126	280	182
Beans				209	265	--	218	277	125
Beef hi-fat w/bone				110	255	--	114	260	94
Egg							218	330	65
Milk, fresh							600	396	390
Milk, evaporated							300	402	205
Chicken							171	369	149

[a] $Kcal_{th}$ limit = 2/3 of total average energy required from complementary foods at each age.

[b] Candidate foods are all those that contain the required amount of nutrient in ≤ the $kcal_{th}$ limit.

[c] Max = maximum g of that food per day ever consumed by a child in Peru (6-11 mo) or Mexico (12-23 mo).

Dry and evaporated milk were the only foods that could supply enough calcium for the 6-11-month-old Peruvian infants (Table 32). Cheese (of which about 130 g would have to be consumed), sardines and dried fish also had the desired calcium density but were not consumed in this location. For the 12-23-month-old group, fresh milk, tortillas and maize dough had an adequate calcium density to meet our criteria. Some children consumed enough fresh milk to supply their recommended calcium intake. Tortillas and maize dough are fairly high in calcium because it is added during food preparation, but the bioavailability of this calcium is probably poor (Rosado et al., 1992).

Table 32. Amounts of calcium-rich foods needed to meet calcium requirements from complementary foods, by age group

	Age (months)								
	6-8			9-11			12-23		
kcal$_{th}$ limit[a]	180			300			500		
Required calcium in complementary foods (mg/d)	336			353			196		
Candidate calcium foods[b]									
	g	**kcal$_{th}$**	**max g**[c]	**g**	**kcal$_{th}$**	**max g**	**g**	**kcal$_{th}$**	**max g**
Milk, powdered	26	96	27	27	101	98	15	56	96
Milk, dried whole	35	173	--	36	181	--	20	101	96
Cheese, fresh	124	170	1	130	179	3	72	99	121
Fish, sardines	80	154	3	84	162	--	47	90	110
Milk, evaporated	129	173	667	135	181	824	75	101	205
Fish, dried	20	66	1	21	70	--	12	39	0
Milk, fresh				307	203	--	170	112	390
Tortilla							112	249	70
Maize dough							113	248	182

[a] Kcal$_{th}$ limit = 2/3 of total average energy required from complementary foods at each age.

[b] Candidate foods are all those that contain the required amount of nutrient in $\leq$ the kcal$_{th}$ limit.

[c] Max = maximum g of that food per day ever consumed by a child in Peru (6-11 mo) or Mexico (12-23 mo)

Because of the relatively high content of vitamin A in breast milk, recommended vitamin A intakes could be met by very small amounts of liver (< 1 g) or leafy greens, assuming that absorption from the latter is adequate (Table 33). Eggs and plantain, and tomatoes (in the 6-8 month age group), also have a high density of vitamin A (or carotene) to meet recommended intakes if consumed in large enough amounts and depending on bioavailability from plant foods. The Mexican preschoolers could also meet their requirements for vitamin A by consuming liver, leafy greens, chili peppers, dried whole milk, eggs, cheese, and plantain. It therefore appears that, when infants and children are consuming average amounts of breast milk with a normal vitamin A concentration, they can meet their recommended vitamin A needs by consuming appropriate complementary foods. However, the amounts needed for some of these foods (e.g. leafy greens, eggs, tomatoes, squash and sardines) would be larger than is likely to be consumed. When breast-milk intake and/or milk vitamin A concentration is low, it would be more difficult to meet vitamin A needs from the complementary foods typically consumed.

Table 33. Amounts of Vitamin A-rich foods needed to meet Vitamin A requirements from complementary foods, by age group

	Age (months)								
	6-8			9-11			12-23		
kcal_{th} limit [a]	180			300			500		
Required Vitamin A in complementary foods (μgRE/d)	13			42			126		
Candidate Vitamin A foods [b]									
	g	**kcal_{th}**	**max g** [c]	**g**	**kcal_{th}**	**max g**	**g**	**kcal_{th}**	**max g**
Beef liver	<1	<1	--	<1	<1	--	<1	<1	72
Pork liver	<1	<1	--	<1	<1	--	<1	1	76
Chicken liver	<1	<1	36	<1	<1	70	2	2	15
Chillies	<1	<1	--	<1	<1	--	3	9	13
Leafy greens	<1	<1	45	<1	1	12	17	5	10
Milk, dried whole	46	29	29	148	93	--	229	151	390
Eggs	13	20	35	42	64	57	66	102	65
Cheese	7	16	1	22	50	3	111	153	121
Plaintain	2	2	6	5	6	--	138	160	525
Tomato	22	4	48	70	13	38	145	30	32
Fish, sardines							147	283	110
Squash, green							435	87	144

[a] Kcal_{th} limit = 2/3 of total average energy required from complementary foods at each age.
[b] Candidate foods are all those that contain the required amount of nutrient in $\leq$ the kcal_{th} limit.
[c] Max = maximum g of that food per day ever consumed by a child in Peru (6-11 mo) or Mexico (12-23 mo)

4.5.5 Summary

It appears that it is practically impossible to supply enough iron from unfortified complementary foods to meet the iron requirements of infants. This is supported by the high prevalence of anaemia in young children in developing countries (WHO, 1994b; Lönnerdal & Dewey, 1995). At 6-8 months in Peru, the iron density of the diet was about one-tenth of that needed. To meet iron needs from iron-rich foods such as liver would require that the infant consume amounts greater than is typically observed for these foods at this age. This conclusion would apply to infants anywhere. In the United States of America, iron deficiency is avoided in part by fortifying infant foods with iron, with the result that the iron density of the diet is about 7 times higher than that in Peru. At 9-11 months the iron density of complementary foods consumed in Peru is similar to that at 6-8 months, but because the desired iron density is lower (Table 27), there is less of a discrepancy between intake and need. In the second year of life, the preschoolers in Mexico consumed complementary foods with an overall iron density of 0.6 mg/100 $kcal_{th}$, which is not much less than the desired density of 0.8 mg/100 $kcal_{th}$. However, the latter value assumes intermediate iron bioavailability, whereas the main sources of iron in the diet of the Mexican children are beans and tortillas (together these supplied about 600 $kcal_{th}$/d) which have very low bioavailability especially when intakes of ascorbic acid are low. For these children the maximum intake of candidate iron foods with higher bioavailability was substantially less than that required (except for beef and pork liver). Although egg appears in Table 30 as a candidate iron food, it should be noted that the bioavailability of iron from eggs is probably also poor.

The situation appears to be similar for zinc at 6-8 months. Again, animal products such as liver and dried fish are the only candidate zinc foods, and the amounts of these foods that infants consume are less than needed (50-70 g/d) to supply adequate zinc. At 9-11 months, although zinc requirements are similar to those of the younger infants, the list of "candidate zinc food" possibilities increases because of the generally higher intake of energy from complementary foods, and includes dry milk, fresh fish and meat. For the Mexican preschoolers the choices increase further but are still limited primarily to animal products. Although no adjustment has been made for the bioavailability of zinc, it is expected to be reasonable from all the foods listed except oats. The low content and bioavailability of zinc in complementary foods may be one reason for growth-stunting in developing countries (Brown, Peerson & Allen, in press).

With regard to calcium, milk products and fish are the only candidate foods at 6-9 and 9-11 months. These could supply enough calcium for Peruvian infants if 120-130 g/d of fresh cheese or 26-36 g/d of dried milk are consumed. This may be difficult at this age. In Mexico, tortillas and maize dough (used to prepare the beverage *atole*) are also possibilities in the second year of life, but the bioavailability of this calcium is probably very poor. The detrimental effects of low calcium intake on the infant and young child remain to be established.

Consuming adequate amounts of vitamin A from liver, eggs or plantain appeared to be feasible in both Peru and Mexico. It bears repeating that our estimates of the desired vitamin A content of complementary foods were calculated using a value (500 µg/L) that reflects the average breast-milk vitamin A content of women in developing countries. However, as discussed in section 4.3.3 and shown in Table 24, breast-milk retinol concentrations have been reported to be only half this value in some regions of the world. Therefore, in these regions the vitamin A density of complementary foods would need to be higher [see section 4.3.4 for a description of how the actual desired density can be estimated]. For example, if milk vitamin A concentration is 250 µg/L, the amount of vitamin A required from complementary foods would be 181, 196 and 262 µgRE/d at 6-8, 9-11, and 12-23 months, respectively (assuming average breast-milk intakes). This would dictate vitamin A densities in complementary foods of 67, 43, and 35 µgRE/100 kcal_{th} at 6-8, 9-11, and 12-23 months, respectively, which are 2-13 times higher than the densities shown in Table 27. Under these circumstances, maternal vitamin A supplementation to increase breast milk concentrations (which is also beneficial to the mother) is an important option to consider.

In this chapter we have presented the values and a general approach that can be used to estimate the desired content and density of all nutrients in complementary foods. We urge the users of this information to substitute values (for breast milk content of Group I nutrients, for example) from their own population when available and appropriate. It is also important that the "problem nutrients" be defined locally using the approach described in section 4.5.3, and that the feasibility of obtaining adequate amounts of nutrients from locally-available foods be examined using a process similar to that described in section 4.5.4. As a cautionary note, though, the “energy limit” used here to identify candidate foods is undoubtedly unrealistically high in most situations, i.e. the assumption, made for purposes of illustration was that they could supply as much as two-thirds of the total energy required from complementary foods. If single foods were to supply most of the energy required this is likely to lead to deficiencies of nutrients low in these foods, e.g. liver is high in iron but low in calcium. Thus it is important to undertake this exercise in the context of the whole diet and considering the need for the most important nutrients, simultaneously.