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WEANING AND CHILD HEALTH

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INTRODUCTION

Weaning has many definitions and usages. Its original meaning probably was a gradual withdrawal of breast milk and introduction of other foods including suitably prepared "adult" foods and the milk of other animals, i.e. the child was weaned from the breast. Some have regarded the introduction of water or fruit juices as the first stage of weaning. The metaphorical use of weaning in other circumstances is used to imply a gradual withdrawal over a period of time of some agent usually to be replaced by something else, e.g. to "wean off" drug dependency. The exact time cannot be pinpointed but the process is nevertheless physiologically essential for normal development; socially, it is a vital rite of passage and may on occasion go wrong.

In this chapter, weaning is regarded as the process of introducing semisolid or solid foods to the breast- or formula-fed child so that in time those new foods contribute a substantial (not defined) amount of the child's energy and nutrient intake. The physiology and natural history of weaning are considered first and the pathologic features of the process second.

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PHYSIOLOGY

Timing

The age at the initiation of weaning varies substantially among societies. Social and anthropologic factors clearly are more important than physiologic ones in determining the age to wean. For simplicity, two main patterns can be described, with a fulcrum at approximately 6 months.

The weaning pattern in developed countries is largely an earlier one, i.e. before 6 months. In Europe and North America, more than 90% of children receive some semisolid foods by the age of 4 months (28, 54), even though professional advice for most children may be to delay semisolid food introduction until after the age of 3–4 months (3, 31). No harm from such early weaning has been demonstrated so long as the children continue to receive either breast milk or a modern infant formula (see "Dietary Renal Solute Load" below). While very early weaning (at less than 3 months) is not necessary, current recommendations are probably historically based rather than based on data indicating that it may cause harm.

Babies who are not weaned until age 3–6 months grow differently from the very early weaners. Cambridge babies who were largely breast fed and then weaned at approximately 16 weeks exhibited slower weight velocities and to a lesser extent slower length velocities than the currently used international anthropometric standards. (These standards are based on USA children, most of whom were probably very early weaners, although the exact nutritional experience is unknown.) The Cambridge babies were thinner but had greater head circumferences (61). The significance of these differences is unclear, but thinner children with larger head circumferences—even if they are a little shorter—might have some nutritional advantages. Comparisons of the growth of children in one area with some external growth standard must be made with caution, however.

Weaning in developing countries may be earlier or later than that in developed countries. The question of which is more suitable is not settled [for review see (45)]. A traditional, later pattern occurs in many developing countries throughout the world in both the poor and the rich areas. In my experience, exclusively breast-fed one-year-old children are not rare in countries as economically diverse as Uganda and Saudi Arabia. Custom rather than economic circumstances must be the driving force, yet the behavioral and anthropologic motives are unclear.

An earlier weaning pattern is emerging in many developing countries, particularly in urban areas. This change may be associated with pressures for mothers to return to paid employment soon after childbearing, but again the behavioral motives are not clear. In an urban area of Gambia, young, illiterate housewives with no other form of employment showed considerable variation in when they weaned their children; the range was from 1 to 46 weeks, with a median of 13 weeks (36). That study reported "an overall tendency for subsequent growth in weight to be adversely affected" in children who began to be weaned before 3 months, a result just the opposite of the slower weight velocity found in the later weaners in the Cambridge study described above.

Foods and Methods

DEVELOPING COUNTRIES Cereals are the most common first weaning food. In developing countries the mother prepares a rice, millet, sorghum, or maize (rarely wheat) gruel. Although these gruels contain polysaccharides and have a reasonable protein-energy ratio, their energy density is low (because of the high water and low fat content of the gruel), and the child would have to eat a considerable bulk to meet energy requirements. Special supplemental weaning foods are available in some countries; they consist mostly of cereals fortified with milk powder, and/or beans and nuts, and/or fat [e.g. Pronutro in South Africa, Incaparina in Guatemala, CSM (corn, soya, milk powder mixture) and CSB (corn, soya, bean mixture) provided by WHO, Thailand weaning package]. The addition of milk both increases the energy density and the protein-energy ratio and improves the overall protein quality. Attempts to reduce the water content of the gruels are difficult, since viscosity is increased, which makes them impossible to eat. Germination, malting, and roasting can reduce viscosity and thus increase the energy density (7, 36). Some weaning foods used in developing countries are almost protein free, e.g. sugar in Jamaica, cassava and taro in Africa and the Pacific, and plantain in Uganda.

EUROPE, NORTH AMERICA Several investigations have defined the diet of the weanling in Europe (6, 15, 27, 29, 40, 41) and North America (24, 48, 63), and some broad conclusions can be drawn.

In the early weanling months, breast milk or more commonly a formula provides a substantial proportion of the total energy and nutrient intake. In later infancy and beyond, this role is taken over by cow's milk, which provides about one quarter of the total energy and one third of the protein intake. Any recommendation concerning the composition of suitable weaning foods must be made against this background. Usually, total energy intakes met the recommended allowances but failed to do so in one of the Canadian studies (63). Boys eat more than girls, and energy intakes tended to be a little higher in less-favored social groups (29). If the child is not taking supplements, the daily intake of vitamin D was frequently below 10 μg (400 IU). The intake of most other nutrients met the recommended dietary allowances (RDA), but iron was an exception; and the British report (15) noted that children who drank little milk had intakes of calcium and riboflavin well below the average. The RDA for protein is set to provide about one tenth of the energy intake, but the observed protein intake exceeds this level in most countries, particularly in later infancy, reflecting the contribution of cow's milk to the total diet.

The average diet of one-year-olds in the United States contained the greatest proportion of formula and, to a lesser extent, the greatest proportion of weaning foods. This fact may explain their higher intakes of iron. Interesting changes occurred in nutrient intake in the United States from 1972 to 1979. While total energy intake showed little change, the type of food eaten to provide this energy changed substantially. In 1972, the average four-month-old received one third of his energy from weaning foods, one fifth from cow's milk, and less than one half from breast milk or formula. In 1979, 60% of the child's energy came from breast milk or formula. These changes, coupled with the reduction of salt added to commercial weaning foods, have led to a reduction in intake of protein, sodium, and calcium.

Similar changes in infant feeding practices have occurred in Europe, with some reduction in protein and calcium intake (6, 29), but there is no objective evidence of a reduction in sodium intake, since this nutrient is rarely recorded in the published data. Similarly there is little data concerning intakes of zinc and copper. Just as in developing countries, cereals are the most commonly used first food, although fruits are favored by some. Cereals are usually highly modified; they are often presented as a powder or as granules of a precooked cereal flour, often with an added "high-protein food" such as milk or soya and sugar. The powder is mixed with water or milk and fed by spoon.

Strained foods are introduced later and are frequently based on full adult meals, e.g. a "lamb dinner" followed by a pudding or dessert that contains fruit and sugar. Parents are therefore able to apply their knowledge of a reasonable mixture of food for adults to their children's diet.

Most children continue to receive breast milk or an infant formula during weaning. In many European countries, the child is switched to a follow-on formula, e.g. the "deuxieme age" formula in France. These formulas tend to be less-modified forms of cow's milk than the starting formulas, e.g. the protein content is often higher than in an infant formula. Since they are fortified with iron and vitamin D, they have advantages over unmodified cow's milk but no advantages over a starting infant formula. Many mothers enjoy seeing their children progress from one food to the other, however, and see it as a laudable development when their babies can leave "baby milk" behind. In these circumstances, a follow-on milk would, in my view, be a far better choice than a change to unmodified whole cow's milk.

A recent unfortunate trend has been the reappearance of the use of skimmed milk during weaning. This practice was once popular in the United States (2) but then disappeared from use. As more adults have taken to drinking skimmed milk to reduce their risks of cardiovascular disease, otherwise well-informed parents have introduced it to their children, sometimes from a very early age. Total energy intakes may decline, and the protein-energy and sodium-energy ratios become very high (see "Dietary Renal Solute Load" below). Continued use of an infant formula could meet all the health wishes of these concerned parents, since infant formula is a low-saturated-fat, low-sodium, sucrose-free food with an adequate energy level.

Current Guidelines and Recommendations

COMPOSITION OF FOODS Since many parents in developed countries rely successfully on commercially prepared weaning foods, various organizations have issued guidelines on the composition of such foods. Internationally, these include the Codex Alimentarius Commission of WHO/FAO (18), the European Society of Paediatric Gastroenterology (17), and the European Economic Community (EEC), which has prepared a draft directive for consultation (59). There are many differences in approach and substance (e.g. expression of nutrients per unit weight or per unit energy and fortification of "natural" foods with vitamins and minerals, particularly vitamin D and iron). Many themes are similar, however, even if the quantitative conclusions differ (e.g. the quality of any added protein and the sodium or sucrose content).

Some individual countries (e.g. France) have issued their own detailed recommendations. Many developing countries have adopted Codex Alimentarius guidelines with suitable modification for local circumstances. For example, the Thai Standard for Infant Foods includes protein not less than 2.5 g per 100 kcal, amino acid score not less than 70% of the FAO/WHO reference pattern, fat 2.6 g per 100 kcal, and linoleic acid not less than 300 mg per 100 kcal. Based on this standard, four supplementary food mixtures have been widely used. Each contains rice with two other ingredients chosen from soya bean, groundnuts, sesame, or mung bean. The use of these mixtures has been associated with a reduction in the prevalence of moderate and severe protein-energy malnutrition (defined on a weight-for-age basis) in preschool children from 15% in 1982 to 3% in 1986. During that time, however, many other programs of child health and of nutritional supplementation were introduced (46). Cameron & Hofvander (9a) described in detail the use of "double mixes" or "triple mixes" during weaning. Most have a cereal base to which is added some animal product such as milk powder or chicken.

TIMING In the 1970s concern focussed on the occurrence of celiac disease at progressively younger ages and the high prevalence of overweight babies. Early weaning was considered a possible contributor to these problems, and in any case little need was seen for it.

British recommendations in 1974 stated, "The early introduction of cereals or other solid foods to the diet of babies before about 4 months of age should be strongly discouraged" (32). More permissiveness was evident in 1981:

> The age at which solid foods are introduced into the diet should be individually determined from a consideration of the method of feeding practices, breast or bottle, the development progress of the baby, and the preference of the mother. It seems likely that the majority of infants should be offered a mixed diet not later than the age of 6 months, and that very few will require solid foods before the age of 3 months (33).

The most recent report has continued this approach (31). The rather arbitrary choice of 4–6 months made in 1974 has, however, been widely accepted. For example, in 1980 the American Academy of Pediatrics (1) stated, "On the basis of present knowledge, no nutritional advantage results from the introduction of supplemental foods prior to 4 to 6 months of age." Waterlow & Thomson (50) have questioned the scientific validity of this timing and argue that few lactating women can supply the energy needs of the baby after 3 months. However, what are the energy requirements of the weanling? Measured intakes are substantially lower than the RDA. Energy intakes when expressed per kilogram of body weight decline rapidly from birth to the age of 6 months, then rise again (perhaps because the child is becoming more active), and eventually coincide with the RDA at about 1 year (62). Perhaps this U-shaped curve reflects true physiologic requirements.

PATHOLOGY

Weaning is clearly physiologically important for the child. Can it go wrong and lead to disease?

Overnutrition

OBESITY Opinions are divided as to whether early weaning predisposes infants to overweight. For example, in Britain some have found a positive relationship (23, 37) and others not (14, 44). In 1971 Taitz (42) concluded there was a relationship, but the relationship was no longer apparent in the same population 7 years later (43). This change with time is particularly interesting, since extensive changes in infant feeding practice occurred during that period in Britain. In particular, bottle-fed babies no longer received unmodified cow's milk; instead, a modern infant formula with a lower solute load was used. Foods with high renal solute loads (see "Dietary Renal Solute Load") may cause thirst and so encourage a larger intake of formula and therefore of energy. In my view, the reduced incidence of rapid weight gain that has occurred in British infants may stem more from the widespread introduction of low-solute milks than from any change in the time of weaning.

During the first year of life, the physiologic deposition of fat rises from approximately 11% of body weight at birth to approximately 25% at 6 months. It then remains steady from ages 6 to 12 months and slowly declines to approximately 16% during the four toddler years (12). Perhaps, then, we have become too concerned about apparent obesity during and after weaning (34). This concern was augmented by the "critical period hypothesis" of adipocyte multiplication in infancy (8); but no such phenomenon has subsequently been confirmed (26).

DIETARY RENAL SOLUTE LOAD Solid foods, particularly those high in protein and electrolytes (e.g. added salt), increase the solute load. So long as these solids are presented after about 3 months of life, the kidney should be able to respond appropriately by producing a more concentrated urine; usually twice the plasma osmolality can be achieved with ease by this age. Theoretically, this change may be followed by increased thirst, which causes the baby to drink more milk or formula. Therefore, far from reducing the infant's reliance on milk or formula, solid foods may actually increase the demand. In practice, this increased demand does not seem to occur in the breast-fed baby, in whom solid foods begin to maintain rather than increase the energy intake as the supply from breast milk begins to diminish either because the mother cannot maintain the output or, more probably, the baby suckles less and so regulates the supply (60). Little such information is available for the formula-fed baby.

In the past (and now rarely) some weanling babies received whole cow's milk, or worse, skimmed milk. Thus, they were receiving much more sodium and protein per unit energy than were babies receiving breast milk or a formula (Table 1) (58). Their urine osmolalities were much higher than those of breast-fed babies, and since urine-concentrating ability was pushed to the limits of the kidney's ability, the plasma osmolalities of the infants were also higher. This effect was compounded in infants who also received weaning foods and therefore had even higher plasma osmolalities (13).

There is no evidence that these higher osmolalities per se are harmful. Concerns have been expressed that high sodium intakes by the weanling would lead to hypertension, but the link has not been proven. Undoubtedly, however, the higher osmolalities reflect a reduced margin of safety in urine-concentrating ability such that should the infant meet another stress to water balance, such as gastroenteritis or high ambient temperatures, the kidney may not be able to concentrate urine further and inappropriately dilute urine could be passed. The final result would be hypernatremic dehydration.

There is good circumstantial evidence that the considerably reduced mortality rates from gastroenteritis and the reduced prevalence of hypernatremic dehydration that occurred in Britain in the 1970s resulted from more extensive use of modern infant formulas with lower renal solutes and, to some extent, the later introduction of solid foods (55, 56).

Table 1 Suppose an older infant requires 600 kcal from milk; what are the options?[a]

Options	Protein (g)	Sodium (nmol)	Saturated fat (g)	Iron (mg)	Vit D (IU)
Breast milk					
800 ml	9	5	17	(-)	—
Infant formula					
800 ml	12	5	16	6	340
Follow-on formula					
800 ml	23	14	16	6	380
Whole cow's milk					
800 ml	27	17	28	—	—
Skimmed milk					
1700 ml	58	38	—	—	—

[a] From Wharton (58).

Undernutrition

PROTEIN-ENERGY MALNUTRITION A detailed review of protein-energy malnutrition cannot be undertaken here. The problem in relation to weaning, however, can be summarized by two questions: Is there sufficient food? Does the food cause diarrhea?

Weaning may often be forced on a mother and her baby because she has insufficient breast milk to satisfy the infant's hunger and nutritional requirements. Whatever food is introduced must adequately replace the "lost" breast milk and adequately supplement the remaining supply. In theory, there are two approaches to this problem: the improvement of lactation and the use of suitable weaning foods.

Programs aimed at improving lactation have been encouraging in the developed world but disappointing in the developing world. Breast-feeding increased in popularity in the developed world, particularly in the late 1970s, after which the increase in popularity slowed between 1980 and 1985. Although the factors governing breast-feeding in relatively affluent societies are complex, perhaps this increase has been a triumph for health education.

In developing countries, the relationship of maternal food intake to lactation has often been studied. There seems only a limited relationship between a mother's food intake and her ability to breast-feed. A strong, healthy baby who suckles frequently and well appears to be the most potent stimulus to prolactin secretion and thus milk secretion.

The perils of feeding infants milk in unclean bottles are well known, but contamination by and proliferation of bacteria in weaning foods, particularly cereal gruels, have received attention only recently. Although many of the contaminating organisms may be harmless, some are pathogenic (e.g. *Bacillus cereus* and *E. coli*), and their association with outbreaks of diarrheal disease have been clearly demonstrated. Many weanlings receive not only a nutritionally inadequate diet but also a contaminated one that could lead to diarrheal disease.

The vital statistics of child health in developing countries illustrate the adverse synergistic effects of malnutrition and infection; this synergism seems to apply particularly to the malnutrition/diarrhea complex. Children born in Europe or North America who are healthy at the age of 4 weeks are very likely to grow up into healthy adults. This likelihood does not hold for the majority of the world's children, those born in developing countries. For them, the post-neonatal months and toddler years pose considerable danger. Much of this international disparity is explained by differing experiences of malnutrition and diarrheal disease. The relationship between malnutrition and such infections as gastroenteritis and measles is sufficiently strong to substantially affect the patterns of child mortality in developing countries (57).

The mechanisms relating the two components of the diarrheal/malnutrition complex are not completely clear. Indeed, many changes in the gastrointestinal tract of malnourished children may reflect not only the nutritional state but also genetic influences and the microbiological environment. I have previously reviewed this relationship in major texts on pediatric gastroenterology (51, 53), but some points bear brief repetition. The pancreatic lesion of kwashiorkor was one of the disease's classic histologic findings, but its functional significance is unclear because hydrolyzed protein is apparently no better absorbed than whole protein, nor do pancreatic enzyme supplements improve fat absorption. Malnourished children have large numbers of bacteria and thus high concentrations of free bile acids in their upper small bowels, but so do their well-nourished friends living in the same environment. A reduction in the duodenal concentration of conjugated bile acids does, however, appear to be a result of malnutrition per se. Although there is good circumstantial evidence that kwashiorkor is associated with partial villous atrophy, there is also no doubt that children (and adults) living in various tropical areas of the world develop partial villous atrophy while remaining reasonably nourished.

Lactase and, to a lesser extent, activities of the other disaccharidases are reduced in malnutrition; this reduction can make a significant contribution to the diarrhea in malnourished children. Many of these children, however, also show a hereditary decline in lactase levels from birth to an ineffectual level, on average, in the later toddler years. This decline occurs in most of the world's children, although Arab, European, and Nilo-Hamitic children are exempt.

Figure 1 illustrates some of the complex effects on the gut of a child's

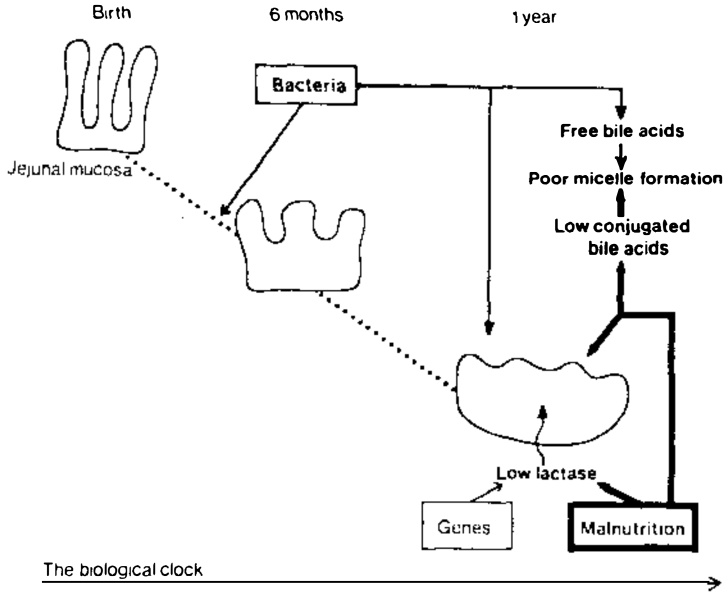

Figure 1. The interplay of genes, nutrition, and the microbiologic environment on jejunal morphology, bile acid metabolism, and jejunal lactase. From Wharton (52).

"genes, clocks and circumstances" (52). That weanling diarrhea is so common seems hardly surprising.

RICKETS Rickets is still common in many areas of the world, even in some very sunny countries. This is particularly true in Middle Eastern countries, but the disease is apparently much less common in Africa. The reason for this disparity is unclear; possibilities include genetic differences and filtering of ultraviolet radiation by a sandy atmosphere. Currently, however, the accepted wisdom is that young women and mothers in the Middle East avoid the hot sunshine, and many live in modern housing which does not provide the seclusion necessary for them to expose even their faces and hands to the sun (5, 16). Consequently, these women are vitamin-D deficient and their infants are born with inadequate stores of vitamin D. The infants receive very little vitamin D in breast milk and similarly are not exposed to the sun. Rickets is almost inevitable. This course of events implies that infantile rickets has its origin in the antenatal period. Assuring the vitamin-D nutrition of the pregnant mother would provide a solid basis for improving this situation.

The frank, classic disease of rickets is now less common in countries in northern latitudes, but very low plasma concentrations of 25-hydroxy-vitamin D ($<$ 10 ng/ml) are frequently reported among immigrant children and their mothers and in indigenous children and their mothers (10, 20, 30, 35, 47).

Sunlight is considered a more important source of vitamin D than the diet, but in Britain, we find that the rise in vitamin D levels during the summer months is only modest in immigrant toddlers, presumably because they make poor use of the limited sunlight. Indeed, dietary vitamin supplements had almost as much effect on plasma 25-hydroxy-vitamin D levels as did the summer (20).

VITAMIN A DEFICIENCY The combined effect of vitamin A deficiency and trachoma is one of the most common causes of blindness in children in the developing world, particularly in the Middle East, the Indian subcontinent, and Southeast Asia. Babies born to vitamin A–deficient mothers have reduced stores of the vitamin in their livers; they receive breast milk containing low concentrations of the vitamin and progress to weaning diets that contain little preformed retinol from animal food. Thus, the child has to rely on the presence in vegetables of β-carotene, which can be converted to retinol. During acute infection, intestinal absorption of the small amount of vitamin in the diet is depressed. The deficiency is usually severe before eye signs appear. Ophthalmic signs include xerosis of the conjunctiva and Bitot's spots, which may lead to corneal necrosis and scarring (keratomalacia) and sometimes perforation and loss of the lens.

Vitamin A deficiency is often accompanied by protein-energy malnutrition, and the reduction in retinol binding protein that is secondary to the protein-energy malnutrition adds transport problems to the overall dietary deficiency. The occurrence of keratomalacia in kwashiorkor is a bad prognostic sign and is associated with a much higher mortality rate. Recent interest has concentrated on the increased mortality in vitamin A deficiency alone, even when it occurs in children with little or mild-to-moderate protein-energy malnutrition (i.e. those with growth failure but excluding the frank syndrome of marasmus and kwashiorkor). In Indonesia relative mortality risk among children with Bitot's spots was seven times that in normal children. An intervention study showed that administration of 200,000 IU of vitamin A led to a one-third reduction in mortality among 1–6-year-olds in treatment villages compared with mortality in the control villages (38, 39). These important observations require confirmation in other environments, if possible by using geographically similar controls.

IRON DEFICIENCY In the first few months of life, the infant has little need for dietary iron but relies on the endowment at birth that is supplied mainly in the form of circulating hemoglobin. From about 4 months, however, this endowment alone is insufficient to maintain the hemoglobin concentration at reasonable levels in the rapidly expanding plasma volume of normal growth. Therefore the child requires a steady supply of dietary iron without which iron stores become depleted. Low serum ferritin levels (an indication of depleted

Table 2 Effect of iron on development

Study variable	Aukett et al (4)	Lozoff et al (27a)	Oski Honig (33a)	Walter et al (49a)	Oski et al (33b)
Criterion of abnormality to enter study	Hemoglobin 8–11 g/dl	Hemoglobin < 10.5 g/dl	Hemoglobin < 10.5 g/dl, mean corpuscular volume ≤ 73 fl, serum iron < 50 μg, and transferrin saturation ≤ 12%	(a) Hemoglobin < 11 g/dl and two abnormal biochemical tests (b) Hemoglobin > 11 g/dl and one or more abnormal test or hemoglobin rise of > 1 g/dl	Hemoglobin > 11 g/dl and (a) normal mean corpuscular volume, electrophoresis, and ferritin (b) normal mean corpuscular volume and electrophoresis and low ferritin (c) normal mean corpuscular volume, high electrophoresis, and low ferritin (d) low mean corpuscular volume, high electrophoresis, and low ferritin
Age group (months)	17–19	6–24	9–26	15	9–12
Treated group (No.)	Anemic; iron deficient (48)	Anemic; iron deficient (15) Nonanemic (19)	Anemic; iron deficient (12)	Anemic; iron deficient (10) Nonanemic; iron deficient (15)	(a) 10 normal (b) 10 iron depleted (c) 10 iron deficient (biochemically) d) 8 iron deficient (biochemically and cellular)

Treatment/day	Oral iron 24 mg + vitamin C	Oral ferrous ascorbate 5 mg/kg plus 'carrier'	Intramuscular iron dextran complex dose dependent on degree of anemia	Oral iron 3–4 mg/kg	Intramuscular iron 50 mg (iron dextran)
Treatment period (days)	60	6–8	5–8	9–15	7
Control group (No.)	Also anemic; iron deficient (49)	Anemic; iron deficient (13) Nonanemic (21)	Iron deficient and anemic (12)	Nonanemic; iron sufficient (12)	Normal as (a) above (10)
Treatment (if any)	Vitamin C 10 mg daily	'Carrier' alone	Intramuscular sterile saline	Oral iron 3–4 mg/kg/day	Intramuscular iron 50 mg (iron dextran)
Psychomotor test	Denver	Bayley scales	Bayley scales	Bayley scales	Bayley scales
Results: treated vs. controls	31% Treated children achieved six or more new skills vs 12% in controls ($p < 0.05$); 37% of those whose hemoglobin rose > 2 g did so vs 16% of those whose hemoglobin rose by < 2 g ($p < 0.05$); 42% effectively treated achieved six or more new skills vs 13% in controls ($p < 0.02$)	Although scores improved in all groups, iron-treated anemia did not increase more than placebo-treated, anemic, or nonanemic (treated or not) groups	Significant increase in mental development index ($p < 0.05$); 66% of treated gained 10 or more points vs 25% of controls	Mental development index improved in treated anemic group ($p < 0.05$). No change in treated controls. No change in treated nonanemic iron-deficient group	77% of treated iron-deficient group increased 10 or more points vs 20% of treated non-iron-deficient group ($p < 0.001$)

stores) are apparent in breast-fed babies by 6 months of age and by 4 months in those receiving unfortified cow's milk.

If other sources of iron are not supplied, iron deficiency anemia eventually occurs. Iron-deficiency anemia in later infancy and the toddler years is common throughout the world. In an inner city area of Birmingham, England, we (4) found 27% of Asian children (i.e. those originally from the Indian subcontinent) aged 18 months were anemic (hemoglobin level less than 11 g/dl); a similar prevalence was found previously in Glasgow, Scotland (19). In Birmingham, however, there was also a high prevalence of anemia (18%) among the indigenous white children. The etiology of the anemia seemed to be simple dietary iron deficiency, which appears to be a worldwide problem, although iron loss from hookworm infestation plays a role in a few countries.

Apart from causing anemia, iron deficiency has other effects. In severe deficiency, lymphocyte and granulocyte function may be depressed, but even mild deficiency is associated with psychomotor impairment. Table 2 summarizes the results of various intervention studies including our own of the effects of iron supplementation on psychomotor function. Although psychomotor delay in deprived urban children is not solely a matter of iron deficiency, this deficiency, unlike many other aspects of deprivation, is at least easy to detect and treat.

Strategies for prevention of iron deficiency (11) are either via health education concerning suitable weaning diets or iron fortification of commonly consumed foods. Health education aims to encourage the consumption of foods from which iron is easily available. Heme iron is a good source of iron, but meat may be limited in weanlings' diets for cultural, religious, or financial reasons. Nonheme iron is present in many vegetables but its availability may be limited unless it is consumed with ascorbic acid or small amounts of meat, fish, or poultry. The efficacy of food fortification again depends on the absorption of the added iron. The fortification of an infant formula or of follow-on milk consumed in later infancy seems to achieve the aim. The fortification of weaning foods is less clear, however. Some physical and biochemical forms of iron are poorly absorbed (e.g. reduced iron, iron pyrophosphate), while others react with the food constituents (e.g. ferrous sulphate) unless they are specially packed. The use of iron fortification has, however, been associated with substantial improvements in the hemoglobin distribution of various communities (11).

ZINC DEFICIENCY Unlike for iron, there is no store of zinc at birth. Therefore, requirements are greater at the time of quicker growth, i.e. during the first 6 weeks or so of life. Afterward they decline to a plateau of approximately 500 μg of absorbed zinc per day during the second 6 months of life, that is, during weaning. Assuming 20% net absorption (which is the average in adults; the figure in weanlings is unknown), a dietary intake of 2–3 mg is advised and is achieved in most weanling diets (21).

Zinc deficiency was first reported in prepubertal boys in the Middle East, where it was associated with short stature and hypogonadism. The evidence concerning zinc deficiency in the otherwise normal weanling (i.e. excluding those with acrodermatitis enteropathica, those receiving parenteral nutrition, and those with frank kwashiorkor) comes mainly from studies of immigrant Mexican children living in Denver (49).

In this study, preschool children who were short for their age received either a zinc supplement or a placebo. The zinc-supplemented group grew more quickly and consumed more. Data concerning zinc nutritional status in preschool children have been reported from few other countries. This lack of data may reflect the problems of defining zinc nutritional status. Plasma zinc levels may not be very reliable indicators, while intervention studies such as those in Denver are very difficult to mount. Low concentrations of plasma zinc have been reported in inner city infants (9) and in 6-month-olds on iron-fortified formulas (22), but concentrations were normal in Asian toddlers in Birmingham (20).

In summary, weaning is a crucial event in the life of an infant. Pathologic effects that can occur at weaning include both overnutrition and undernutrition. All of these syndromes are caused by the use of weaning foods of inappropriate nutrient quality and quantity. Use of foods too high in energy, protein, or electrolytes can produce overnutrition syndromes. Use of foods inadequate in protein, calories, vitamin D, vitamin A or B-carotene, iron, and zinc can produce their respective undernutrition syndromes. Parents and health practitioners must be alert to the need for proper weaning foods at the correct time, as well as the dangers of a badly formulated weaning diet.

Literature Cited

1. American Academy of Pediatrics, 1976. Committee on Nutrition. Iron supplementation for infants. *Pediatrics* 58:765–68
2. Anderson, T. A., Fomon, S. J., eds. 1974. *Infant Nutrition,* pp. 80–81, 408–34. Philadelphia: Saunders
3. Astier-Dumas, M., Fernandes, J., Marquardt, P., Nordio, S., Oppé, T. E., et al. 1983. First report of the Scientific Committee for food on the essential requirements of infant formulae and follow up: milks based on cows milk proteins. In *Food Sci. Tech.,* pp. 9–32. *Rep. Sci. Comm. Food,* 14th Ser., EUR 8752 EN. Luxembourg: Comm. Eur. Communities
4. Aukett, M. A., Parks, Y. A., Scott, P. H., Wharton, B. A. 1986. Treatment with iron increases weight gain and psychomotor development. *Arch. Dis. Child.* 61:849–57
5. Belton, N. R., Elidrissy, A. T. H., Gaafar, T. H., Aldres, A., El-Swailem, A. R., et al. 1982. Maternal vitamin D deficiency as a factor in the pathogenesis of rickets in Saudi Arabia. In *Vitamin D Chemical, Biochemical and Clinical Endocrinology of Calcium Metabolism,* pp. 735–37. New York: de Gruyter
6. Black, A. E., Billewicz, W. Z., Thomson, A. M. 1976. The diets of preschool children in Newcastle-upon-Tyne 1968–71. *Br. J. Nutr.* 35:105–13
7. Brandtzaeg, B., Malleshi, N. G., Svanberg, U., Desikachar, H. S. B., Mellander, O. 1981. Dietary bulk as a limiting factor for nutrient intake—with special

reference to the feeding of preschool children. III. Studies of malted flour from ragi, sorghum and green gram. *J. Trop. Pediatr.* 27:184–89

8. Brook, C. G. D., Lloyd, J. K., Wolf, O. H. 1972. Relationship between age of onset of obesity and size and number of adipose cells. *Br. Med. J.* 2:25–27
9. Butrimovitz, G. P., Purdy, W. C. 1978. Zinc nutrition and growth in a childhood population. *Am. J. Clin. Nutr.* 31:1409–12

9a. Cameron, M., Hofvander, Y. 1971. *Manual on Feeding Infants and Young Children*. Geneva: FAO/WHO. 156 pp.

10. Cockburn, F., Belton, N. R., Purvis, R. J., Giles, M. M., Brown, J. K., et al. 1980. Maternal vitamin D intake and mineral metabolism in mothers and their newborn infants. *Br. Med. J.* 281:11–14
11. Dallman, P. R. 1986. Iron deficiency in the weanling: A nutritional problem on the way to resolution. *Acta Paediatr. Scand. Suppl.* 323:59–67
12. Dauncey, M. J., Gandy, G., Gairdner, D. 1977. Assessment of total body fat in infancy from skinfold thickness measurements. *Arch. Dis. Child.* 52: 223–27
13. Davies, D. P. 1973. Plasma osmolality and feeding practices of healthy infants in the first three months of life. *Br. Med. J.* 2:340–42
14. Davies, D. P., Gray, O. P., Elwood, P. C., Hopkinson, C., Smith, S. 1977. Effects of solid foods on growth of bottle-fed infants in first three months of life. *Br. Med. J.* 2:7–8
15. Department of Health and Social Security. 1975. A nutrition survey of preschool children in 1967–68. *Rep. Health Soc. Subj.* No. 10, p. 74, p. 79, p. 86, p. 89. London: HMSO
16. Elidrissy, A. T. H., Sedrani, S. H., Lawson, D. E. M. 1984. Vitamin D deficiency in mothers of rachitic infants. *Calcif. Tissue Int.* 36:266–68
17. European Society of Paediatric Gastroenterology and Nutrition, Committee on Nutrition, 1981. Guidelines on infant nutrition II: Recommendations for the composition of follow-up formula and Beikost. *Acta Paediatr. Scand. Suppl.* 287:1–38
18. Food and Agricultural Organization/World Health Organization. 1976. Rep. of Food Standards Programme, Codex Alimentarius Commission. Recommended international standards for foods for infants and children, pp. 11–23. Rome: FAO/WHO
19. Goel, K. M., Logan, R. W., House, F., Connell, M. D., Stevens, E., et al. 1978. The prevalence of haemoglobinopathies, nutritional iron and folate deficiencies in native and immigrant children in Glasgow. *Health Bull.* 36:176–82
20. Grindulis, H., Belton, N. R., Scott, P. H., Wharton, B. A. 1986. Combined deficiency of iron and vitamin D in Asian toddlers. *Arch. Dis. Child.* 61: 843–48
21. Hambidge, K. M. 1986. Zinc deficiency in the weanling: How important? *Acta Paediatr. Scand. Suppl.* 323:52–58
22. Hambidge, K. M., Walravens, P. A., Casey, C. E., Brown, R. M., Bender, C. 1979. Plasma zinc concentrations of breast-fed infants. *J. Pediatr.* 94: 607–8
23. Hodgson, S. V. 1978. Early infant feeding and weight gain. *J. R. Coll. Gen. Pract.* 28:280–81
24. Johnson, G. H., Purvis, G. A., Wallace, R. D. 1981. What nutrients do our infants really get? *Nutr. Today* 16:4–26
25. Deleted in proof
26. Knittle, J. L., Timmers, K., Ginsberg-Fellner, F., Brown, R. E., Katz, D. P. 1979. The growth of adipose tissue in children and adolescents. *J. Clin. Invest.* 63:239–46
27. Lestradet, H., Machinot, S., Grenech, M. O., Duforu, C., Six, M. F. 1979. L'alimentation des nourissons francais de 2 a 9 mois. *La Rev. Pediatr.* 15 (1):11–19

27a. Lozoff, B., Brittenham, G. M., Viteri, F. E., Wold, A. W., Urrutia, J. J. 1982. The effects of short term iron therapy on developmental deficiency in iron deficient anemic infants. *J. Pediatr.* 100: 351–57

28. Martinez, G. A. quoted by Fomon, S. J. 1987. Reflections on infant feeding in the 1970's and 1980's. *Am. J. Clin. Nutr.* 46:171–82
29. McKillop, F. M., Durnin, J. V. G. A. 1982. The energy and nutrient intake of a random sample (305) of infants. *Hum. Nutr: Appl. Nutr.* 36A:405–21
30. O'Hare, A. E., Uttley, W. S., Belton, N. R., Westwood, A., Levin, S. D., Anderson, F. 1984. Persisting vitamin D deficiency in the Asian adolescent. *Arch. Dis. Child.* 59:766–70
31. Oppe, T. E., Arneil, G. C., Baum, J. D., Lowr, R., Martin, J., et al. 1988. Present day practice in infant feeding: Third report. *Dep. Health Soc. Secur. Rep. Health Soc. Subj.* 32:1–66
32. Oppe, T. E., Arneil, G. C., Creary, R. D. G., Lloyd, J. K., Stroud, C. E., et al. 1974. Present day practice in infant feeding. *Dep. Health Soc. Secur. Rep.*

Health Soc. Subj. No. 9. London: HMSO

33. Oppe, T. E., Arneil, G. C., Davies, D. P., Laurance, B. M., Lloyd, J. K., et al. 1980. Present day practice in infant feeding—1980. *Dep. Health Soc. Secur. Rep. Health Soc. Subj.* No.20. London: HMSO

33a. Oski, F. A., Honig, A. S. 1978. The effects of therapy on the developmental scores of iron deficient infants. *J. Pediatr.* 92:21–25

33b. Oski, F. A., Honig, A. S., Helu, B., Howanitz, P. 1983. Effects of iron therapy on behavior performance in non anemic, iron deficient infants. *Pediatrics* 71:877–80

34. Poskitt, E. M. E. 1986. Obesity in the young child: Whither and whence? *Acta Paediatr. Scand. Suppl.* 323:24–32

35. Poskitt, E. M. E., Cole, T. J., Lawson, D. E. M. 1979. Diet, sunlight, and 25-hydroxy vitamin D in healthy children and adults. *Br. Med. J.* 1:221–23

36. Rowland, M. G. M. 1986. The weanling's dilemma: Are we making progress? *Acta Paediatr. Scand. Suppl.* 322:33–42

37. Shukla, A. P., Forsyth, H. A., Anderson, C. M., Marwah, S. M. 1972. Infantile overnutrition in the first year of life: A field study in Dudley, Worcestershire. *Br. Med. J.* 4:507–15

38. Sommer, A., Tarwotjo, I., Djunaedi, E., West, K. P., Loeden, A. A., et al. 1986. Impact of vitamin A supplementation on childhood mortality: A randomised controlled community trial. *Lancet* 1:1169–73

39. Sommer, A., Tarwotjo, I., Hussaini, A., Susanto, D. 1983. Increased mortality in mild vitamin A deficiency. *Lancet* 2:585–88

40. Steenbergen, W. M. Van. 1978. De voeding van Surinaamse. Antiliaanse en Nederlandse zuigelingen in de Bijlmermeer. *Voeding* 39:2–8

41. Stolley, H. 1982. Zeitpunkt und Zusammensetzung der "Beikost" für Säuglinge in I. Lebensjahr. Uit: *Säuglingsernährung Heute*, ed. R. Grultner, pp. 17–34. Berlin/Heidelberg/New York: Spring-Verlag

42. Taitz, L. S. 1971. Infantile overnutrition among artificially fed infants in the Sheffield region. *Br. Med. J.* 1:315–16

43. Taitz, L. S., Lukmanji, Z. 1981. Alterations in feeding patterns and rates of weight and gain in South Yorkshire infants 1971–1977. *Hum. Biol.* 53:313–20

44. Thorogood, M., Clark, R., Harker, P., Mann, J. I. 1979. Infant feeding and overweight in two Oxfordshire towns. *J. R. Coll. Gen. Pract.* 29:427–30

45. Underwood, B. A., Hofvander, Y. 1982. Appropriate timing for complementary feeding of the breast-fed infant: A review. *Acta Paediatr. Scand.* 1982: (Suppl. 294):1–32

46. Valyasevi, A. 1988. Nutritional problems during weaning period in Thai children. *Hong Kong J. Paediatr.* 1 (Suppl.):88–94

47. Verity, C. M., Burman, D., Beadle, P. C., Holton, J. B., Morris, A. 1981. Seasonal changes in perinatal vitamin D metabolism, maternal and cord blood biochemistry in normal pregnancies. *Arch. Dis. Child.* 56:943–48

48. Vobecky, J. S., Vobecky, J., Demere, P. P., Shapcott, D., Blanchard, R., Black, R. 1980. Food and nutrient intake of infants in the first fifteen months. *Nutr. Rep. Int.* 22(4):571–80

49. Walravens, P. A., Krebs, N. F., Hambidge, K. M. 1983. Linear growth of low income preschool children receiving a zinc supplement. *Am. J. Clin. Nutr.* 38:195–201

49a. Walter, T., Kovalskys, J., Stekel, J. 1983. Effect of mild iron deficiency on infant mental development scores. *J. Pediatr.* 102:519–22

50. Waterlow, J. C., Thomson, A. M. 1979. Observations on the adequacy of breast feeding. *Lancet* 2:238–42

51. Wharton, B. A. 1975. Gastroenterological problems in children of developing countries. In *Paediatric Gastroenterology*, ed. C. M. Anderson, V. Burke, pp. 569–610. Oxford: Blackwell

52. Wharton, B. A. 1976. Genes, clocks and circumstances—the effect of over and under nutrition. In *Early Nutrition and Later Development*, ed. A. W. Wilkinson, pp. 112–23. Tunbridge Wells, Engl.: Pitman Medical

53. Wharton, B. A. 1977. Effect of malnutrition on structure and function. In *Essentials of Paediatric Gastroenterology*, ed. J. T. Harries, pp. 130-40. London: Livingstone

54. Wharton, B. A. 1982. A quinquennium in infant feeding. *Arch. Dis. Child.* 57:895–97

55. Wharton, B. A. 1982. Past achievements and future priorities—a view of present day practice in infant feeding 1980. In *Nutrition and Health—A Perspective*, ed. M. R. Turner, pp. 169–81. London: MTP

56. Wharton, B. A. 1983. Food for the suckling: Revolution and development. *Acta Paediatr. Scand.* 299:5–10

57. Wharton, B. A. 1986. Food for the weanling—the next priority in infant nutrition. *Acta Paediatr. Scand. Suppl.* 323:93–98
58. Wharton, B. A. 1987. Nutrition in the 1980's. *Nutr. Health* 5:211–20
59. Wharton, B. A., Oppe, T. E., Astier-Dumas, M., Fernandes, J., Hildebrandt, A., et al. 1989. Food Sci. Tech. Rep. Sci. Comm. Food, 14th Ser. Luxembourg: Comm. Eur. Communities. In press
60. Whitehead, R. G., Paul, A. A. 1988. Diet and growth of healthy infants. *Hong Kong J. Paediatr.* 1(Suppl.):1–20
61. Whitehead, R. G., Paul, A. A., Ahmed, E. A. 1986. Weaning practices in the United Kingdom and variations in anthropometric development. *Acta Paediatr. Scand. Suppl.* 323:14–23
62. Whitehead, R. G., Paul, A. A., Cole, T. J. 1981. A critical analysis of measured food energy intakes during infancy and early childhood in comparison with current international recommendations. *J. Hum. Nutr.* 35:339–48
63. Yeung, D. L., Pennell, M. D., Hall, J., Leung, M. 1982. Food nutrient intake of infants during the first 18 months of life. *Nutr. Res.* 2:3–11