

Symposium: Accomplishments in Child Nutrition during the 20th Century

Infant Feeding in the 20th Century: Formula and Beikost¹

Samuel J. Fomon

Department of Pediatrics, College of Medicine, University of Iowa, Iowa City, IA 52242

ABSTRACT The early years of the 20th century were notable for improvements in general sanitation, dairying practices and milk handling. Most infants were breast-fed, often with some formula feeding as well. Availability of the home icebox permitted safe storage of milk and infant formula, and by the 1920s, feeding of orange juice and cod liver oil greatly decreased the incidence of scurvy and rickets. Use of evaporated milk for formula preparation decreased bacterial contamination and curd tension of infant formulas. From 1930 through the 1960s, breast-feeding declined and cow's milk and beikost were introduced into the diet at earlier and earlier ages. Although commercially prepared formulas, including iron-fortified formulas replaced home-prepared formulas, few infants were breast-fed or formula fed after 4–6 mo of age. Iron deficiency was prevalent. From 1970 through 1999, a resurgence of breast-feeding was associated with a prolongation of formula feeding and an increase in usage of iron-fortified formulas. By the end of the century, formula feeding of older infants had largely replaced feeding of fresh cow's milk and the prevalence of iron deficiency had greatly decreased. *J. Nutr.* 131: 409S–420S, 2001.

KEY WORDS: • *infant feeding* • *breast-feeding* • *infant formula* • *beikost*

In 1948 when I began my pediatric residency, I had little awareness of the history of infant feeding during the first half of the 20th century. Since then, I have collected small bits of information in relation to specific interests at the time. As a research fellow in renal physiology, I studied osmotic diuresis and reviewed the literature on renal solute load, including the reports concerning infants. In the 1950s, when I was involved with Charlie May in metabolic balance studies with normal infants, I reviewed the older reports on intakes and excretion of protein, fat and some of the major minerals. However, despite all the effort I invested over the years in trying to define desirable characteristics of infant formulas, I did not attempt an interpretive review of the history of infant feeding; even in my 1993 book (Fomon 1993), I relied primarily on reviews by other authors for events that occurred before about 1950. Thus, the thoughts presented here as they relate to the first half of the 20th century require some indulgence of the readers. I am on firmer ground during the second half of the century.

Among the most important advances in infant nutrition and feeding during the latter half of the 20th century were the increase in breast-feeding and the nutrition and feeding of

preterm infants—areas to be covered in other presentations in this symposium. Although important advances were also made in feeding of infants with chronic disease, my presentation is restricted to nutrition and feeding of normal term infants.

A number of changes in public health during the latter half of the 19th century contributed to more successful formula feeding of infants in the early part of the 20th century (Fomon 1993). Most important of these were improvements in general sanitation, disposal of garbage and, at least in some cities, chlorination of water. Handling and storage of milk improved. The biochemical differences between the major components of human milk and cow's milk had been defined. Even at the beginning of the 20th century, it was generally appreciated that infant formulas based on cow's milk required the addition of water and carbohydrate. A number of commercially prepared formulas were patented. Liebig's food for infants, marketed in 1867 as a liquid and subsequently as a powder, consisted of wheat flour, cow's milk, malt flour and potassium bicarbonate (Forsyth 1910–1911, Smith 1885). Other formulas were introduced in rapid succession; by 1883, 27 brands of patented infant foods were available (Bracken 1953). However, relatively few infants were fed commercially prepared formulas.

The years 1900–1930

In 1900, general sanitation and dairying practices, although better than in the past, were still quite primitive by current standards. Seamless rubber nipples, which could be fitted over the necks of feeding bottles had become available but were apparently not widely used (Brennemann 1912); thus, cleaning of bottles and nipples was generally unsatisfactory. Means

¹ Presented at the symposium, Accomplishments in Child Nutrition during the 20th Century, given at Experimental Biology 2000, April 15–19, 2000 in San Diego, CA. This symposium was sponsored by the American Society for Nutritional Sciences. The proceedings of this symposium are published as a supplement to *The Journal of Nutrition*. Guest editors for the supplement publication were Buford L. Nichols, Baylor College of Medicine, Houston, TX and Frank R. Greer, University of Wisconsin, Madison, WI.

² Abbreviations used: AAP, American Academy of Pediatrics; CFR, Code of Federal Regulations; FDA, Food and Drug Administration; WIC, program for women, infants and children.

for safe storage of formula in the home were not generally available, and adulteration of milk was common. The possibility that inadequate intakes of vitamins or of trace minerals could lead to disease had not been considered. As stated by Langworthy in 1898 (McCollum 1957), it was generally believed that "Foods have a dual purpose: Building and repair. Energy for heat and work. Foods consist of the nutrients protein fat and carbohydrates and various mineral salts."

Although reliable data on the prevalence of breast-feeding during the early years of the 20th century are not available, comments in the literature suggest that most infants were breast-fed throughout most of y 1 of life, many of them also being fed some formula [see, e.g., Friedenwald and Ruhrah (1905)]. A survey of a number of urban centers in 1912–1919 indicated that at 12 mo of age, 13% of infants were exclusively breast-fed and 45% were partially breast-fed (Yankauer 1994).

There is reason to believe that formula feeding in the early 1900s was less successful in the United States than in Europe. In Europe, at least in Germany, milk was almost uniformly boiled for use in infant formulas, whereas in the United States, raw milk was most commonly used (Brennemann 1911). The strong prejudice against the use of heat-treated milk was based on the observation that scurvy occurred primarily in infants fed sterilized, condensed or pasteurized milk (American Pediatric Society 1898).

The early years of the 20th century were notable in the United States for the adoption by many physicians of a complex sequence of changes in formula composition, the "percentage method" or "American method" of formula feeding (Rotch 1907). The aim was to provide a formula with a composition close to that of human milk but taking into account the digestive capability of the individual infant. Nevertheless, the major emphasis was on the ratios of protein, fat and carbohydrate and not on energy density; formulas commonly ranged from <50 kcal/dL to >80 kcal/dL. Formula preparation was so complex that it was commonly performed in commercial laboratories dedicated to this purpose. With the endorsement of Rotch, the Walker-Gordon Farm had been established in 1891 for the production of clean milk (Morse 1935) and Walker-Gordon Laboratories, which used this milk, were in operation in many cities in the early 1900s (Friedenwald and Ruhrah 1905, Morse 1935). In retrospect, although the system of formula preparation was unnecessarily complex, the formulas prepared by the Walker-Gordon Laboratories were made with care, were unlikely to be seriously contaminated with pathogens and were therefore generally more satisfactory than formulas made in the home. For all its prominence in the literature, this "American Method" of formula prescription was not widely used in rural areas nor by less affluent families in urban areas. Thus, the majority of formula-fed infants received formulas made in the home from whole milk or "top milk" (i.e., milk with 7–10% fat). Because the tough curd formation associated with feeding cow's milk protein presented a greater problem to the infant than the digestion of butterfat, the use of "top milk" resulted in more digestible formulas.

By 1912, clean milk was generally available in New York City (Rosen 1958) and it seems likely that similar improvements in dairying practices and milk handling had occurred in much of the United States. Rubber nipples that could be readily cleaned had come into widespread use (Brennemann 1912), and safe storage of milk in many homes had become possible because of the availability of the kitchen icebox (Fig. 1). The important contribution on the energy requirements of infants (Rubner and Heubner 1899) had gained general recognition and at least some physicians recommended an energy

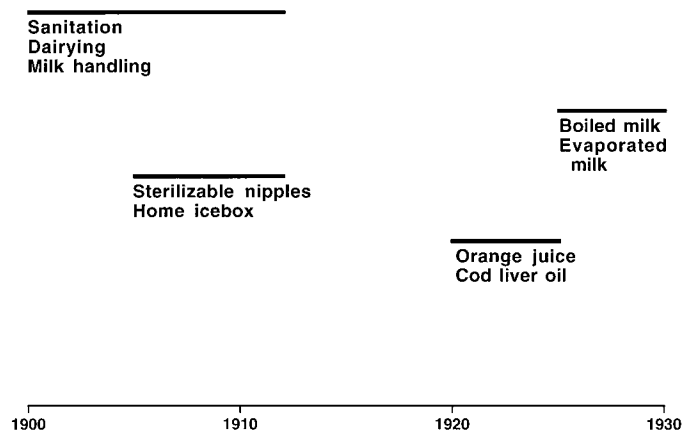


FIGURE 1 Changes in infant feeding and nutrition from 1900 to 1930: major improvements in sanitation, dairying practices and milk handling occurred from 1900 to 1912; sterilizable rubber nipples and the home icebox became widely available by 1912; beginning in the early 1920s, feeding of orange juice and cod liver oil resulted in decrease in the prevalence of scurvy and rickets, and use of boiled or evaporated milk in formula preparation from the mid-1920s resulted in infant formulas with lower curd tension and less bacterial contamination.

intake of 100 kcal/(kg · d) during the first few months of life and somewhat lesser intakes per unit of body weight subsequently (Brennemann 1912). Nevertheless, even in the 1920s, formulas varied considerably in energy density. Those fed from 1924 to 1929 to infants under the care of the Infant Welfare Society of Chicago (Grulee et al. 1934) were no >53 kcal/dL, whereas formulas made from whole milk with added Karo syrup (Marriott and Davidson 1923) or from evaporated milk diluted 1:1 with water and the addition of Karo syrup (Marriott 1927) provided nearly 100 kcal/dL.

Vitamins

As reviewed by McCollum (1957), a number of animal studies in the late 1800s and early 1900s had demonstrated that, despite the scientific consensus of the time, diets containing protein, fat, carbohydrate and mineral salts were inadequate to support life. An enlightened view was presented by Hopkins (1906): "The animal body is adjusted to live either on plant tissues or on other animals, and these contain countless substances other than proteins, carbohydrates and fats. Physiologic evolution, I believe, has made some of these well nigh as essential as are the basal constituents of the diet." In 1912, Funk (1912) suggested that beriberi, scurvy, pellagra and possibly rickets were caused by deficiency in the diet of special substances for which he proposed the name, "vitamines."

Scurvy. Although scurvy of the adult had been recognized as early as 1734 [citation of Bachstrom by Stewart and Guthrie (1953)], the relation between infantile scurvy and scurvy of the adult was slow to be recognized. It was largely through the efforts of Hess that it became customary in the 1920s to supplement the diets of infants with fruit or vegetable juices (McCollum 1957). The prevalence of infantile scurvy then decreased substantially.

Rickets. As urban living in the United States increased during the late 1800s and early 1900s, infantile rickets increased. The Russian pediatrician, Schabad, in a series of reports published between 1908 and 1912, demonstrated that cod liver oil was effective in curing and preventing rickets (Holt 1963). In 1920, Mellanby (1920) demonstrated that a

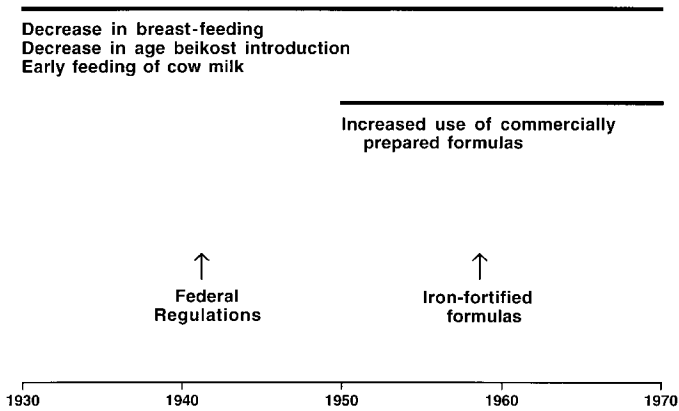


FIGURE 2 Changes in infant feeding and nutrition from 1930 to 1970: breast feeding declined, whereas beikost and fresh cow's milk were introduced at earlier and earlier ages. The first federal regulations concerning infant formulas went into effect in 1941 and, beginning in 1950, commercially prepared formulas began to replace home-prepared formulas. Iron-fortified formulas were introduced in 1959.

fat-soluble substance could prevent rickets in puppies; in 1922, McCollum and co-workers (1957) demonstrated that the fat-soluble substance was not vitamin A. Use of cod liver oil as a prophylactic measure against rickets became widespread in the United States by the mid-1920s.

Other developments before 1930

By the mid-1920s, when it was known that infantile scurvy could be prevented by daily feeding of fruit juices, the prejudice against use of boiled milk in infant formulas disappeared and formula feeding became much more successful. To modify curd tension, lactic acid was commonly used. The use of lactic acid rather than lime water for modifying curd tension may have occurred because of the advantage of acidified over alkalized formulas in inhibiting bacterial growth.

Evaporated milk was first marketed by Gail Borden in 1858 (Wharton 1941); beginning in 1885, it was sold in hermetically sealed cans sterilized by heat. However, because of fear of producing scurvy, it was not used in infant feeding until the 1920s, when its use was promoted by several of the leading pediatricians of the time (Brenneman 1929, Marriott 1927, Marriott and Schoenthal 1929). Evaporated milk was relatively inexpensive, could be stored at room temperature and was free of bacterial contamination until the can was opened. The processes of evaporation, homogenization and heat treatment resulted in physical changes in the milk, with an increased percentage of casein adsorbed to the surface of the fat globules (Council on Foods 1937a), thus contributing to the reduction in curd tension.

Beikost

Although cereal was commonly included as a constituent of infant formulas in the early 1900s, the purpose of its inclusion was the reduction of curd tension, not as an energy source. With the use of evaporated milk for infant formulas, cereal was no longer needed. On the basis of her review of the literature, Adams (1959) stated that until the 1920s, the usual feeding pattern in the United States was introduction of sieved vegetable soup by the end of y 1, potato at ~18 mo and other vegetables not until 2 y of age or later. She pointed out that in Holt's *The Diseases of Infancy and Childhood*, the recommended age for introduction of green vegetables in the 1911 edition

was 36 mo, but that by the 1929 edition, the age had decreased to 9 mo. However, it is evident that earlier introduction of beikost was common at least in some areas. Infants under the care of the Infant Welfare Society of Chicago between 1924 and 1929 received cereal at 5 mo of age and a vegetable at 6 mo of age (Grulee et al. 1934).

The years 1930–1970

Various developments in infant feeding and nutrition from 1930–1970 are indicated in **Figure 2**. Although data on the percentage of infants who were breast-fed in the United States from 1930 to 1950 are less satisfactory than later data, there is no question that the trend was downward. Data from the National Fertility Study (Hirschman and Hendershot 1979, Hirschman and Butler 1981), indicate that from 1931 to 1935, >70% of first-born infants and a somewhat lesser percentage of second-born infants were initially breast-fed and 40% of infants were breast-fed for at least 6 mo. By 1946–1950, initial breast-feeding of first-born infants had decreased to 50% and only 20% were breast-fed for at least 6 mo. A survey of hospitals carried out in 1945 (Bain 1948) indicated that 69% of infants discharged ≤7 d after birth were breast-fed and 60% of infants discharged >7 d after birth were breast-fed. The data of Bain regarding percentage of infants initially breast-fed are based on a review of discharge records and therefore are likely to be more accurate than the recall data of Hirschman and co-workers (Hirschman and Hendershot 1979, Hirschman and Butler 1981). During the 1950s and 1960s, the trend in breast-feeding was steadily downward, and by the early 1970s, only ~25% of infants were breast-fed at age 1 wk and only 14% between 2 and 3 mo of age (**Fig. 3**).

Home-prepared infant formulas

From the 1930s or early 1940s, most formulas fed to infants in the United States were prepared by mixing evaporated milk or fresh cow's milk with water and adding carbohydrate. A typical evaporated milk formula, as prepared in 1949, when I was a pediatric resident, included 1 can (13 fl oz) of evaporated milk, 19 fl oz of water, and ~1 oz of carbohydrate, usually in the form of corn syrup (Karo) or sucrose. Such a formula

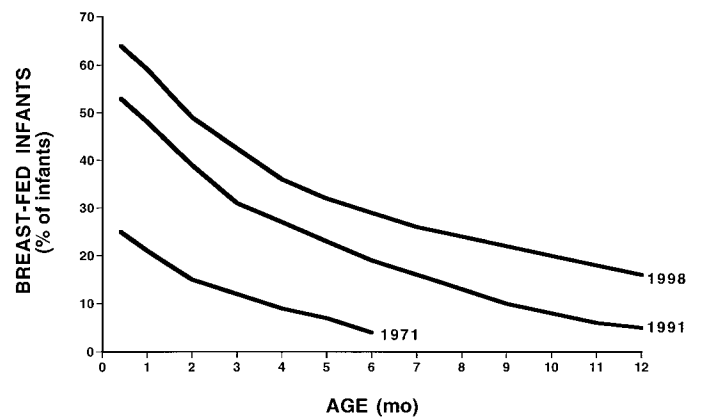


FIGURE 3 Exclusively and partially breast-fed infants as percentage of all infants in 1971, 1991 and 1998. Data for 1971 from Martinez and Krieger (1985) and for 1991 from personal communication from Ross Mothers' Survey (Greenbaum, S., 1992, Ross Products Division, Columbus, OH). A smoothed curve is presented for 1998 based on data from personal communications from Boettcher, J. A. (1999, Mead Johnson Nutritionals, Evansville, IN) and the Ross Mothers' Survey (Ryan, A., 2000; Ross Products Division, Columbus, OH).

Downloaded from jn.nutrition.org by on July 10, 2009

JN THE JOURNAL OF NUTRITION

provided ~67 kcal/dL, with 15% of energy from protein, 42% from carbohydrate and 43% from fat. Home-prepared formulas were sometimes made with cow's milk (usually pasteurized and homogenized) rather than with evaporated milk. These formulas provided about the same distribution of energy from protein, fat and carbohydrate as did the evaporated milk formulas. Most evaporated milk and most pasteurized, homogenized whole cow's milk were fortified with vitamin D. Orange juice was given as a source of vitamin C.

Improved general sanitation, safe supplies of water and milk, and better understanding of both microbiology and nutrient requirements resulted in a high degree of success with formula feeding, and it was the opinion of most physicians and the general public that formula feeding was about as safe and satisfactory as breast-feeding. However, the infant formulas in general use in the 1950s were associated with a number of problems unappreciated by physicians and parents, including the following: 1) the high potential renal solute load placed the infants, especially young infants, at risk of developing hypernatremic dehydration during illness (Fomon and Ziegler 1999); 2) the low content of iron in the formulas together with the high intake of inhibitors of iron absorption (Fomon 1993) were responsible for a high prevalence of iron deficiency and, in the case of whole-milk formulas, probably with the added problem in some infants of increased intestinal blood loss (Ziegler et al. 1990); 3) intakes of essential fatty acids were low. In addition, scurvy continued to be seen. A survey of 226 teaching hospitals in the United States indicated that during the years 1956–1960, 713 infants and children were admitted to these hospitals because of scurvy (Committee on Nutrition 1962).

Commercially prepared formulas

Milk-based formulas. From the late 1800s, a number of commercially prepared formulas were available in the form of powders that merely required the addition of water before being ready to feed to infants. Many of these formulas had been developed in an attempt to mimic the chemical composition of human milk, and several researchers had focused their attention on the greater percentages of low-molecular-weight fatty acids in cow's milk than in human milk, believing that these were responsible for the poor tolerance of infants to butterfat (Gerstenberger et al. 1915). Thus, even in the early 1900s, formulas free of butterfat had been marketed. The cost of powdered formulas was appreciably greater than that of formulas made from evaporated milk or whole cow's milk, and usage of commercially prepared formulas was rather low. However, beginning in 1951, when concentrated liquid formulas (133 kcal/dL) were introduced, considerations of convenience began to supersede considerations of cost, and the popularity of commercially prepared formulas increased dramatically (Fig. 4). By 1960, concentrated liquid formulas had largely replaced powdered formulas (Fig. 4). The change from home-prepared formulas to commercially prepared formulas was accelerated by the introduction in 1959 of iron-fortified formulas and the vigorous promotion of these formulas by the formula industry and by pediatricians (Andelman and Sered 1966, Committee on Nutrition 1971). By the late 1960s, <10% of infants were fed home-prepared formulas (Fig. 5).

From at least the 1930s (Powers 1935) until the 1950s, the protein concentration of human milk was believed to be greater than is now known to be the case, and many pediatricians believed that cow's milk protein was so inferior to human milk protein for meeting the needs of infants that infants fed formulas required a considerably greater intake of protein than

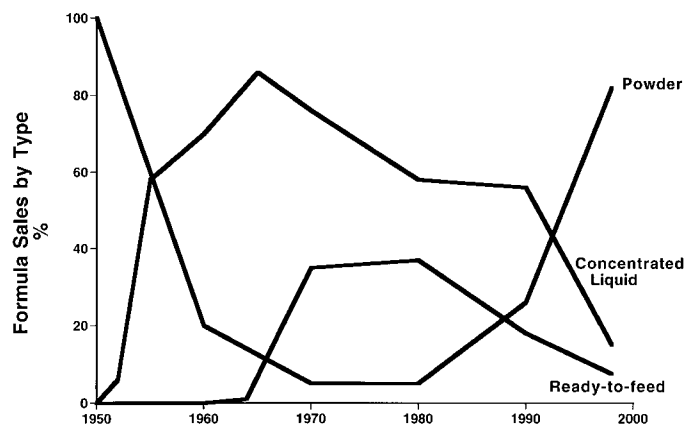


FIGURE 4 Commercially prepared formula sales by type from 1950 to 1998: powder, concentrated liquid (133 kcal/dL) and ready-to-feed (67 kcal/dL). Data through 1987 based on Ross Mothers' Survey, personal communication from Martinez, G. A. (1989, Ross Products Division, Columbus, OH); subsequent data based on personal communication from Boettcher, J. A. (2000, Mead Johnson Nutritionals, Evansville, IN).

did breast-fed infants. Protein content of a number of widely used formulas ranged from 3.3 to 4.0 g/100 kcal and several formulas recommended for use in management of infants with diarrhea provided 5.7–6.3 g/100 kcal (Fomon 1967). During the late 1950s and early 1960s, most of the leading commercially prepared formulas fell into one of two classes. One class (e.g., Lactum, Mead Johnson) consisted of formulas similar to home-prepared evaporated milk formulas but with added vitamins; the other class (e.g., Similac and SMA) were of lower protein content and contained a mixture of vegetable and oleo oils with added vitamins and minerals. The gradual takeover of the market by the latter formulas seems not to have been based on considerations of nutrient requirements or renal solute load, but on the unpleasant odor of regurgitated butterfat after its partial digestion and on the impression that formulas similar to the home-prepared evaporated milk formulas led to constipation.

As early as 1923, James Gamble had gained at least some understanding of renal excretion of solutes (Abt 1965), but it was not until the 1950s that the relation of renal solute load to water balance in infants received serious consideration (Cooke et al. 1950, Darrow et al. 1954, Pratt et al. 1948), and not until the 1960s that renal solute load began to be considered in the design of infant formulas. However, even at the end of the century, infant formula regulations permitted the marketing of formulas with undesirably high potential renal solute load. In 1998, an Expert Panel recommended to the Food and Drug Administration (FDA) that infant formulas provide a potential renal solute load (i.e., solutes of dietary origin that would require renal excretion if none were diverted into growth and none were lost through nonrenal routes) no >33 mosm/100 kcal (Raiten et al. 1998). Although the FDA took no immediate action on this recommendation, the upper limit of 33 mosm/100 kcal is well above that of formulas marketed during the last 20 y of the 20th century. However, most of the formulas fed in the first half of the 20th century exceeded this maximum and undoubtedly contributed to the prevalence of hypernatremic dehydration.

An iron-fortified formula was introduced in the United States in 1959; by the mid 1960s, most manufacturers offered the same base formula with or without substantial iron fortification (Fomon 1967). Many parents and physicians were

reluctant to use iron-fortified formulas because they believed that feeding such formulas was responsible for constipation, fussiness and intestinal disturbances in the infants. Studies that failed to confirm such adverse effects (Nelson et al. 1988, Oski 1980) did not seem to change the prejudice against iron-fortified formulas.

Recognizing that human milk has a preponderance of whey proteins, whereas cow's milk has a preponderance of caseins, a milk-based formula with a whey/casein ratio similar to that of human milk was introduced in the United States in 1962 and by the mid 1990s, whey-predominant formulas became the rule. Nevertheless, the whey proteins of cow's milk are quite different from those of human milk; even today, rather meager evidence exists that a milk-based formula with added whey proteins results in a product that is superior to a milk-based formula without the additional whey proteins.

Nonmilk-based formulas. A formula based on soy flour was developed by Hill as a feeding for infants allergic to cow's milk and became commercially available in 1929 (Abt 1965). Formulas prepared from soy flour were pale tan in color and had a nutty odor. Parents complained that the formulas produced loose, somewhat malodorous stools, and resulted in staining of the reusable cloth diapers that were in general use. Excoriation of the diaper area was common. The stool characteristics resulted primarily from the presence of considerable amounts of fiber in the soy flour. In addition to soy-based formulas, a meat-based formula and a casein hydrolysate formula were marketed. Several of these special formulas were not fortified with vitamins when initially marketed, apparently because pediatric allergists believed that the vitamin mixes used for vitamin fortification of formulas might include allergens. In the 1950s and 1960s, a number of vitamin deficiencies were described (Fomon 1993). In addition, goitrogens present in soy flour were responsible for development of goiters in infants fed a soy flour-based formula unfortified with iodine. A few cases of vitamin K deficiency were reported in the 1940s in infants fed a meat-base infant formula (protein from beef heart) or a casein hydrolysate formula before these formulas were fortified with vitamin K (Fomon 1993).

Formulas prepared with isolated soy protein became commercially available in the United States in the mid-1960s and within 10 y almost completely replaced soy flour-based formulas. Isolated soy protein-based formulas are similar in color to milk-based formulas and are nearly odorless. Because most of the fiber is removed during the protein isolation process, the infant's stools are generally similar to those of infants fed milk-based formulas. However, the process employed in isolation of the protein resulted in elimination of most of the vitamin K that had been naturally present in the soy flour-based products, and a few cases of vitamin K deficiency were reported before the products were fortified with vitamin K (Fomon 1993). Development of nutrient deficiencies in infants fed milk-free formulas was responsible in part for the development of a series of federal regulatory actions on nutrient content of infant formulas.

Governmental regulations concerning infant formulas

The United States was among the last of the major industrialized countries to implement federal regulations concerning safety of infant formulas (Miller 1989). It was not until 1938 that the new Food and Drug Act included reference to foods for special dietary purposes, including infant formulas. In 1941, the FDA declared that a food sold for use by infants should include a label declaration for moisture, energy, protein, fat,

available carbohydrates, fiber, calcium, phosphorus, iron and vitamins A, B-1, C and D.

In 1952 and 1953, an alteration in the method of heat treatment of concentrated liquid SMA resulted in a decrease in vitamin B-6 content, and clinical manifestations of vitamin B-6 deficiency developed in a number of infants (Fomon 1993). As a result of this experience, the FDA in 1962 published a proposed revision of the 1941 regulations. A revised final regulation published in 1966 included the requirement for minimal levels of 11 vitamins and minerals; because of controversy over the regulations, however, it was not put into effect (Miller 1989). Instead, the FDA asked the Committee on Nutrition of the American Academy of Pediatrics (AAP) to recommend levels of nutrients in infant formulas. The report of the Committee on Nutrition (1967) was used as a basis for public hearings in 1968–1969, and the final regulation, published in 1971 (FDA 1971) included minimum requirements for protein, fat, linoleic acid and 17 vitamins and minerals.

Commercial formula services and the development of ready-to-feed formulas. Throughout the first half of the 20th century, hospitals maintained formula laboratories to prepare formulas for newborns and other formula-fed infants. This activity required special equipment, was labor intensive and presented formidable problems in quality control. In the early 1950s, commercial formula services began operating in a number of metropolitan areas in the United States (Committee on Nutrition 1965) and many hospitals elected to use these services rather than to continue their own activities in formula preparation. By the early 1960s, considerable discussion centered about the cost effectiveness of purchasing ready-to-use formulas from outside sources rather than preparing them intramurally (Fomon 1993). It was evident that use of a commercial formula service influenced the choice of stock formula selected by a hospital. For example, if an evaporated milk formula was offered at \$0.09/bottle while a commercially prepared formula was offered at \$0.12/bottle (the approximate purchase price in the early 1960s), the less expensive formula was likely to be chosen. Manufacturers of various prepared formulas were therefore motivated to develop competing feed-

ing systems. In 1963, the Mead Johnson Company introduced the Beneflex system of feeding in which bulk quantities of any infant formula manufactured by that company could be transferred aseptically to feeders suitable to the needs of individual infants (Fomon 1993). Soon afterward, the formula manufacturers were able to offer sterile ready-to-feed formulas in disposable bottles with disposable or reusable nipples. These were first used in hospitals but were subsequently made available to the general public. An indication of the rapid rise in sales of ready-to-feed formulas during the late 1960s and early 1970s may be seen from Figure 5. The data in the figure apply to consumer sales and do not include hospital usage. Early in 1965, approximately equal numbers of hospitals in the United States used ready-to-feed formulas supplied by manufacturers and formulas supplied by locally operated commercial formula services. By 1970, nearly all of the locally based commercial formula services had ceased to exist, few hospitals prepared their own formulas intramurally and most newborn nurseries used commercially prepared, ready-to-feed formulas.

Cow's milk

Comprehensive data on the percentage of infants fed cow's milk at various ages in the 1940s through the 1960s are not available, but Harris and Chan (1969) in a limited survey

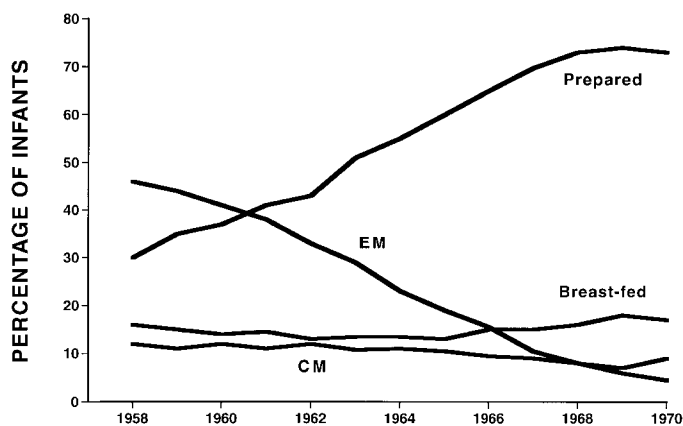


FIGURE 5 Percentage of 2- to 3-mo-old infants receiving various forms of feeding from 1958 to 1970: feeding of commercially prepared formulas (prepared) increased and feeding of formulas based on evaporated milk (EM) decreased. Relatively few infants were breast-fed and few young infants were fed cow's milk (CM). Data based on Ross Mothers' Survey, personal communication from Martinez, G. A (1989, Ross Products Division, Columbus, OH).

found that 60% of infants were fed whole milk by 4 mo of age. The percentage may not have been quite as high for the entire country. In 1971, >30% of infants from 3 to 4 mo of age, >40% of infants from 4 to 5 mo of age and ~60% of infants from 5 to 6 mo of age were fed cow's milk (Fig. 6). On the basis of data from various sources, I estimated that in 1975 (Fomon 1975), 58% of 5- to 6-mo-old infants were fed cow's milk.

Because it was not yet appreciated that feeding of homogenized, pasteurized cow's milk to young infants could predispose to dehydration during illness and to development of iron deficiency, there seemed therefore little reason not to change at an early age from feeding formula to feeding fresh cow's milk. Cow's milk was considerably less expensive than infant formula, required no mixing and was a staple item in the home. Moreover, many parents probably considered that the ability of an infant to tolerate at a young age a diet more closely approaching that of older children was an index of infant development and maturity.

Beikost

Following the trend of the previous two decades, the recommended age for introduction of beikost continued to decrease from 1930 to the early 1970s. In 1935, Marriott (1935) suggested mo 5 or 6 as an appropriate age for introduction of solid foods, and in 1937 the American Medical Association (Council on Foods 1937b) stated that pediatricians favored feeding of strained fruits and vegetables at ~4-6 mo of age. Beal (1957) reported that in an upper socioeconomic group in Denver, strained foods were offered to the infant at increasingly early ages during the years 1946 through 1955, and this seemed to be a general trend. Among pediatricians responding to a survey in 1954, feeding of solids was recommended before 8 wk of age by 66% and before 3 mo of age by 88% (Butler and Wolman 1954). Most extreme were the recommendations of Sackett (1953), who promoted feeding of cereal at 2-3 d of age, strained vegetables at 10 d and strained fruits at 17 d. In 1963, Epps and Jolley (1963) reported that when infants were seen for a first health visit at 1-2 mo of age in the Child Health Clinics of the District of Columbia, 83% were already receiving beikost. On the basis of a survey in Rochester,

Minnesota, in the late 1960s, Harris and Chan (1969) reported that nearly 80% of infants were being fed cereal by 1 mo of age. In 1975, I estimated that 5- to 6-mo-old infants obtained 40% of energy intake from beikost (Fomon 1975). Such a diet can be calculated to be generous in protein and carbohydrate and relatively low in fat (Fomon et al. 1990). Because few infants were fed iron-fortified formulas (or any formulas) after 5 or 6 mo of age, beikost contributed most of the dietary iron for most infants, and dry powdered cereals fortified with iron were the major contributors.

In the 1940s and 1950s, infant cereals were fortified with sodium iron pyrophosphate or other insoluble iron compounds of low bioavailability; beginning in 1972, the cereals were fortified with electrolytic iron powder (Committee on Nutrition 1976b). On the basis of a report by Rios et al. (1975) that electrolytic iron powder was as well absorbed by infants as was ferrous sulfate, it was generally assumed that regular feeding of iron-fortified cereals could meet the infant's need for iron. Therefore, most physicians saw no objection to feeding cow's milk.

Throughout the 1960s, salt, monosodium glutamate, sugar and modified food starches were included in the preparation of many commercially available strained and junior foods. Salt, monosodium glutamate and sugar were presumably added to satisfy the preferences of adult taste panels, and the modified food starches were used to achieve and maintain the desired physical appearance, consistency and texture of the products. The manufacturers voluntarily discontinued the use of monosodium glutamate in 1969. In 1970, a subcommittee of the Food Protection Committee, Food and Nutrition Board, National Academy of Sciences/NRC recommended an upper limit of 0.25% for salt added to commercially prepared infant foods (Filer 1971a) and concluded that, when used in accordance with federal regulations, there was no toxicologic basis for excluding modified food starches from the diets of infants (Filer 1971b). Over the next few years, the manufacturers adjusted their formulations to decrease the concentration of salt in infant foods. The downward trend in addition of salt was accompanied by a downward trend in addition of sugar. By 1977, the addition of salt had been discontinued, and sugar was added to fewer products and in smaller amounts than previously. The decrease in addition of sugar resulted in a considerable decrease in the energy density of some products, e.g., strained fruits provided an average of 82 kcal/100 g in 1972 and only 54 kcal/100 g in 1984 (Anderson and Ziegler

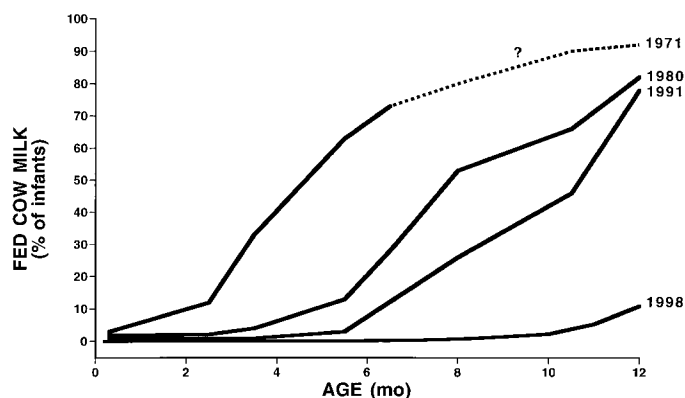


FIGURE 6 Infants fed cow's milk (no breast-feeding, no formula feeding) as percentage of all infants in 1971, 1980 and 1991. Data for 1971 and 1980 from Martinez et al. (1981); data for 1991 based on personal communication from Ross Mothers' Survey (Greenbaum, S., 1992, Ross Products Division, Columbus, OH).

1987). By the late 1970s, all manufacturers had reduced the number of beikost items to which modified food starches were added, and had discontinued use of all but a few types of modified starches.

American Academy Committee on Nutrition

In 1954, soon after I arrived in Iowa as an assistant professor in the Department of Pediatrics, the chairman of the department, Charles D. May, was asked by the executive director of the AAP to serve as chairman of a new committee of the Academy, the Committee on Nutrition, which had been established by the Executive Board of the Academy on April 1, 1954 (Executive Board 1956). In those days, the AAP operated in a much less formal mode than was to be the case in later years, and May was given complete freedom in choosing members, mostly from pediatric departments, to serve on the committee. A liaison group of scientists and administrators was also established with individuals from governmental agencies, including the FDA and the infant food industry. With the aid of suggestions from May, the Executive Board of the Academy in 1956 outlined the scope of the Committee activities as follows: "This Committee shall concern itself with standards for nutritional requirements, optimal practices and the interpretation of current knowledge as these affect infants, children and adolescents."

The first report of the Committee, "Ethics and etiquette in advertising" (Committee on Nutrition 1956) was written by May. The second report, "Water requirement in relation to osmolar load as it applies to infant feeding" (Committee on Nutrition 1957), I prepared at May's request. Fortunately, the report did not acknowledge that I was the author because I had included calcium and magnesium as components of the renal osmolar load. It was the first of a series of gradually improving statements that I, and later Ziegler and I, published on the topic. The second chairman of the Committee was Charles U. Lowe (1957-1960) and I was the third chairman (1960-1962). During those early years, the reports of the Committee were primarily educational and did not include policy statements. It was not until the mid 1960s that the Committee finally gained nutritional prominence through its assistance to the FDA in defining nutritional requirements for infant formulas and in setting policy for nutritional practices relating to infants, children and adolescents. During the last quarter of the 20th century, the Committee on Nutrition exerted an enormous influence on child nutrition, most notably on aspects of infant feeding.

The years 1970-1999

Infant feeding in the United States during the last 30 y of the 20th century was marked by increases in breast-feeding and formula feeding and a decrease in feeding of cow's milk (Fig. 7). The increase in breast-feeding in industrialized countries in the 1970s was worldwide, and the reasons for the increase after several decades of decline are not easy to identify. The movement toward increased breast-feeding seemed to arise from the general public rather than from health professionals, and may have been in part associated with negative publicity directed against the formula industry. The formula industry was accused of interfering with breast-feeding in lesser industrialized countries by its aggressive marketing of infant formulas (Joseph 1981, McComas 1988). In the 1970s in the United States, the National Council of Churches' Interfaith Center on Corporate Responsibility and the Infant Formula Action Coalition mounted an effective public awareness cam-

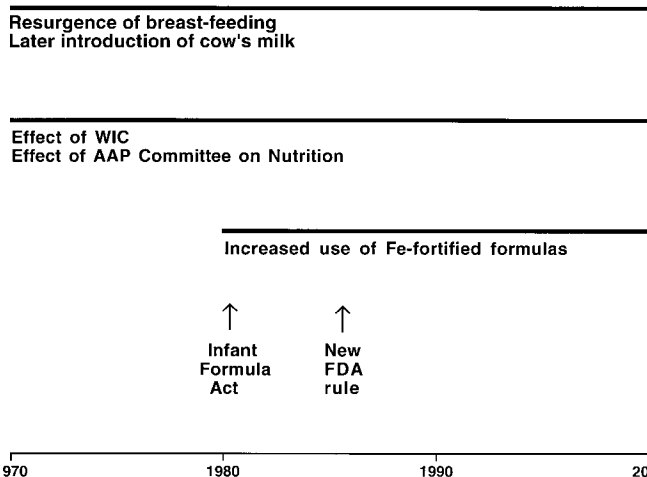


FIGURE 7 Changes in infant feeding and nutrition from 1970 to 2000: breast-feeding increased, although the duration of breast-feeding was generally <6 mo and was commonly accompanied by formula feeding. The change from breast- or formula feeding to feeding of cow's milk occurred at progressively later ages. The women, infants and children (WIC) program included a larger and larger percentage of infants from low income families and contributed to increased breast-feeding and use of iron-fortified formulas in this group. The American Academy of Pediatrics (AAP) Committee on Nutrition provided guidance to the Food and Drug Administration (FDA) on the nutrient content of infant formulas and issued policy statements on infant feeding, including one that contributed to the later introduction of cow's milk. Federal regulations on infant formulas included the Infant Formula Act of 1980 and a new regulation in 1985 on nutrient content of infant formulas.

paign. Likely in response to this new climate, the infant formula manufacturers increased their efforts to promote breast-feeding.

Federal regulations regarding infant formulas

Just as new regulations had been developed after the outbreak of vitamin B-6 deficiency in formula-fed infants in the early 1950s, the occurrence of chloride deficiency in formula-fed infants in the 1970s (Fomon 1993) resulted in new regulations regarding infant formulas. In 1976, the Committee on Nutrition revised and extended its recommendations regarding nutrient content of infant formulas (Committee on Nutrition 1976a). An amendment (PL 96:359) to the Food, Drug and Cosmetic Act, referred to as the Infant Formula Act of 1980, gave the FDA authority to establish quality-control procedures for infant formula manufacturing, to establish recall procedures, to establish and subsequently to revise, if necessary, nutrient levels and to regulate labeling.

A task force of the AAP submitted revised recommendations on nutrient content of infant formulas to the FDA in 1983 (Forbes and Woodruff 1985). The final rule, published 2 years later FDA (1985), specified minimum concentrations of 29 nutrients and maximum concentrations of 9 of these nutrients. In 1998, an Expert Panel made recommendations for revision of the Code of Federal Regulations (CFR) as it applied to the nutrient content of infant formulas (Raiton et al. 1998). This Expert Panel suggested a number of revisions of the upper and lower limits for nutrients already specified in the CFR, recommended an upper limit for potential renal solute load, a change in the assessment of protein quality and the addition of upper limits for most nutrients. As the 20th century ended, the FDA had taken no action on these recommendations.

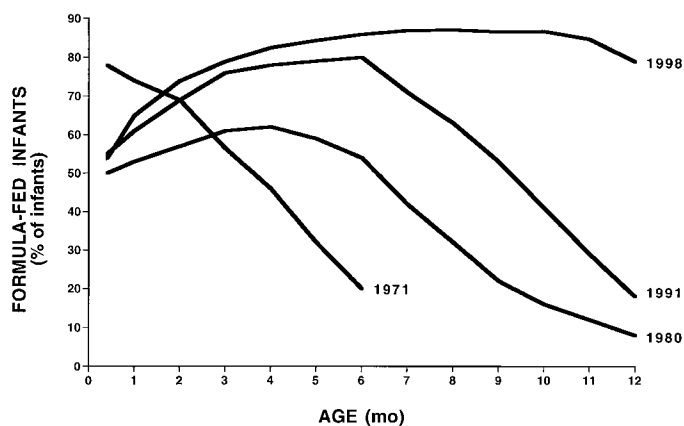


FIGURE 8 Formula-fed infants (including infants also breast-fed) as a percentage of all infants in 1971, 1980, 1991 and 1998. Data for 1971 and 1980 from Martinez et al. (1981); data for 1991 based on personal communication from Ross Mothers' Survey (Greenbaum, S., 1992, Ross Products Division, Columbus, OH); data for 1998 based on personal communication from Boettcher, J. A. (2000, Mead Johnson Nutritionals, Evansville, IN).

Formation and growth of the WIC program

In response to the "Hunger in America" publicity in the 1960s, a federal program was designed to aid women and children whose health was at risk because of inadequate nutrition. Included were pregnant and lactating women, other women during the first 6 mo postpartum, and infants and children to age 4 y (later, to age 5 y). This program (WIC, women, infants and children),³ funded at a level of \$20 million/y during 1973 and 1974, was administered by the Food and Nutrition Service of the USDA. By the end of 1974, WIC was in operation in all but a few states, and in 1975 it was established as a permanent national health and nutrition program. The program served only a modest fraction of infants in 1975 (103,000 infants), but the number increased to 0.78 million in 1984 (Richman et al. 1986) and to 1.99 million in 1996 (Randall et al. 1998), representing about 47% of live births. From the beginning, the food package for formula-fed infants included iron-fortified infant formula and iron-fortified cereal. By the late 1980s, the WIC program exerted a major influence on improvements in infant feeding.

Infant formulas

In 1971, when <25% of infants in the United States were initially breast-fed and only ~14% were still breast-fed between 2 and 3 mo of age (Fig. 3), nearly all of the remainder were fed commercially prepared formulas for 4–6 mo and then were fed cow's milk. The trend toward increased breast-feeding beginning in 1971 was associated with a decrease in formula feeding of infants during the first 2 or 3 mo of life; however, there was a concurrent deferment in the age of introduction of cow's milk and the percentage of infants fed formulas after 4 mo of age increased. As may be seen from Figure 8, 20% of 6-mo-old infants were formula fed in 1971 and >50% were formula fed in 1980.

Characteristics of formulas most commonly fed. Until the 1980s, only Wyeth Laboratories marketed a whey-predominant, milk-based formula in the United States. Whey-predom-

inant formulas were introduced by other companies in the 1980s and 1990s and by the mid 1990s, nearly all milk-based formulas contained added whey proteins. From the time of introduction of isolated soy protein-based formulas in the mid-1960s until the end of the 20th century, these formulas were much more widely used in the United States than in most other countries. Although data that separate isolated soy protein-based formulas from several other special formulas are not available, it seems likely that in 1991 >20% of formula-fed infants were fed isolated soy protein-based formulas (Fomon 1993). More recent data are not available. The speculation that generous intakes of isoflavones from soy-based products might exert adverse effects on infant development (Setchell et al. 1997) appears to have been taken more seriously in other countries than in the United States.

Iron deficiency. Iron deficiency in infancy in the United States has always been most prevalent among infants in low income families, presumably at least in part because these infants are inclined to be of lower birth weight and therefore, as a group, begin life with lower iron stores than infants from higher income families. In the 1950s and 1960s, as already mentioned, most infants were fed cow's milk beginning at 4–6 mo of age and this practice extended into the early 1970s. Although national survey data for infants are not available, three surveys of 12- to 36-mo-old children conducted between 1968 and 1980 (Owen et al. 1974, Pilch and Senti 1984, Singer et al. 1982) demonstrated that iron deficiency was relatively common. In the 1976–1980 national survey, slightly >10% of children from 1 to 2 y of age were anemic (hemoglobin concentration < 110 g/L) and the great majority of these children were iron deficient (Pilch and Senti 1984). In the 1988–1994 survey, only 3% of children from 1 to 2 y of age demonstrated iron-deficiency anemia (Looker et al. 1997). I concluded in 1987 (Fomon 1987b) and still believe it most likely that the origin of the iron deficiency in these children was during y 1 of life, when absorption of dietary iron was insufficient to meet the infant's needs.

Although sales of iron-fortified formulas increased progressively from 40% of all formula sales in 1971 to 64% in 1975, 72% in 1980 and 79.5% in 1985 (Fomon 1987b), this increase exerted only a modest effect on prevention of iron deficiency until, in the 1980s, formula feeding began to be extended well beyond 6 mo of age. Figure 9 presents data on the percentage of formula-fed infants receiving iron-fortified formulas at various ages in 1971, 1980 and 1991. I have been unsuccessful in obtaining data for 1998 or 1999, but there is little question that the percentage of infants fed iron-fortified formulas was quite high in the last few years of the 20th century. Much of the increase in number of infants fed iron-fortified formulas from 1971 to 1991 can be accounted for by the increased enrollment in WIC, because it is evident that many of these infants would otherwise have been fed cow's milk. In 1992, the Committee on Nutrition (1992) published a forthright recommendation that all nonbreast-fed infants be fed iron-fortified formulas until 12 mo of age, and this statement probably exerted a major influence on pediatricians caring for infants not enrolled in WIC.

Powdered vs. concentrated liquid formulas. Beginning about 1970, use of concentrated liquid formulas declined, whereas use of powdered and ready-to-feed formulas increased (Fig. 4). By the early 1970s, the physical properties of formula powders had been improved to the extent that they were much more readily suspended in water. The increased use of powdered formulas after 1971 coincided with the increase in breast-feeding. Powdered formulas are commonly used to make up an occasional formula feeding for breast-fed infants and

³ Early history of the WIC program was obtained from the web page, www.usda.gov.

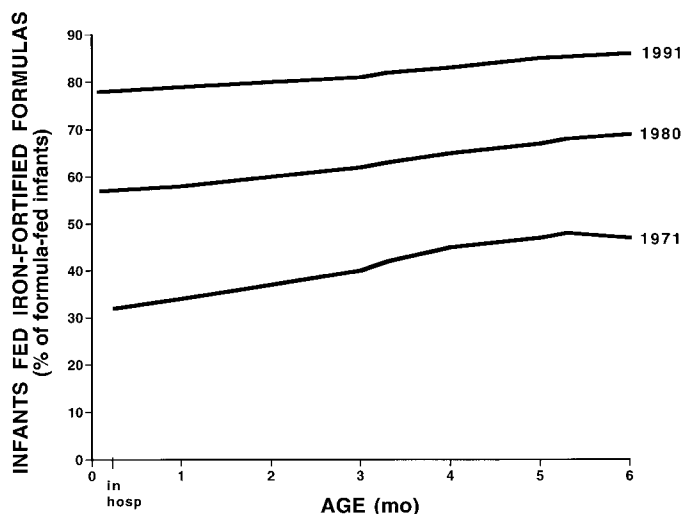


FIGURE 9 Infants fed iron-fortified formulas as percentage of formula-fed infants in 1971, 1980 and 1991. Data for 1971 and 1980 based on personal communication from Martinez, G. (1989, Ross Products Division, Columbus, OH); data for 1991 based on personal communication from Ross Mothers' Survey (Greenbaum, S., 1992, Ross Products Division, Columbus, OH).

many mothers may have continued to use powdered formulas after cessation of breast-feeding.

Cow's milk

The trend away from early introduction of cow's milk was steady and impressive from 1971 through 1998 (Fig. 6). As already mentioned, the resurgence of breast-feeding that began in 1971 was associated with deferment of the age of introduction of cow's milk. Initially, it seemed that the change was probably more related to inclinations of parents rather than a reflection of recommendations by pediatricians. My speculation is that a mother who elected to breast-feed her infant initially was convinced that it would be better to feed formula than cow's milk when she discontinued breast-feeding. The explosion of information about components of human milk and about the many probable nutritional and nonnutritional benefits of breast-feeding accelerated in the 1970s. As summarized elsewhere (Fomon et al. 1981), a number of studies reported in the 1960s had demonstrated that consumption of cow's milk, especially large quantities of cow's milk, could provoke gastrointestinal blood loss in infants with iron-deficiency anemia, but it had not been demonstrated that similar provocation of gastrointestinal blood loss occurred in noniron-deficient infants consuming moderate quantities of cow's milk. Moreover, as already mentioned, the iron of infant cereals was believed to be able to meet the infant's needs. Thus, it was generally recommended (Committee on Nutrition 1976b, Fomon et al. 1979) that for nonbreast-fed infants >6 mo old, formula feeding was desirable, but cow's milk plus regular feeding of iron-fortified cereals was a satisfactory alternative. Although one might have inferred from several reports (Berenberg et al. 1969, Bruck et al. 1968, Colle et al. 1958, Pratt et al. 1948) that infants fed cow's milk were at risk of hypertonic dehydration during episodes of diarrhea, it seemed reasonable to recommend that additional water be given during illness rather than to insist that feeding cow's milk be prohibited as a food for normal infants.

In the 1960s and early 1970s, a number of physicians recommended the feeding of skim milk to infants beginning at

4–6 mo of age, presumably motivated by the desire to treat real or imagined obesity or to prevent development of obesity or atherosclerosis (Fomon 1974). We carried out a study (Fomon et al. 1977) in which infants were fed from 4 to 6 mo of age a skim milk modified by the addition of a small amount of safflower oil and fat-soluble vitamins, and demonstrated that the infants consumed enormous quantities of the milk and of beikost, gained in length at a normal rate but gained in weight at a slower rate than did normal infants. Most impressive was the loss of skinfold thickness, suggesting that the infants were using body fat stores to make up for the energy deficit of the diet. We speculated that persistence with such a diet was likely to be seriously detrimental to the infants. The Maternal and Child Health Service distributed reprints of our report widely to child health clinics but whether this had any effect on the practice is difficult to determine. In any case, with the increase in breast-feeding and associated changes in attitude toward infant feeding in the 1970s, the practice of feeding milk with decreased fat content became uncommon.

In 1981, we found evidence that fresh pasteurized cow's milk provoked blood loss in apparently normal infants (Fomon et al. 1981) and, largely on the basis of this report and a subsequent one (Ziegler et al. 1990), the Committee on Nutrition (1992) recommended that infants who were not breast-fed should be given iron-fortified formulas rather than fresh cow's milk throughout y 1 of life. Actually, provocation of gastrointestinal blood loss may not be as important in the development of iron deficiency in infants fed fresh cow's milk as is the presence in cow's milk of large amounts of bovine proteins and calcium, which are known to be potent inhibitors of nonheme iron absorption (Cook et al. 1991, Hallberg et al. 1991, Hurrell et al. 1989b). As early as 1968, a question had been raised about the bioavailability of electrolytic iron powder of intermediate particle size (Elwood et al. 1968), the iron used to fortify dry infant cereals, and in the 1980s, several authors (Fomon 1987a, Hurrell 1984, Hurrell et al. 1989a) concluded that this iron was probably of low bioavailability.

Beikost

In the early 1970s, most infants in the United States were fed beikost by 6 wk of age (Brown and Hughes 1972, Fomon 1975, Jerome et al. 1972, Valentine and Valentine 1972). The increase in breast-feeding during the 1970s and early 1980s in the United States was accompanied by a somewhat later introduction of beikost. Beikost was introduced into the diet later for breast-fed than for formula-fed infants (Fomon 1993, Sarrett et al. 1983).

Infant cereal is generally the first beikost item offered to infants, and the age at which it is introduced is therefore an indication of the age of introduction of beikost. Changes in the age of introduction of cereal from 1976 to 1991 are shown in **Figure 10**, which is based on a survey carried out from 1976 to 1980 (Sarrett et al. 1983) and unpublished data from 1991 (Boettcher, J. A., personal communication). The unpublished data also include age of introduction of cereal in 1999, and these values are remarkably similar to those for 1991. Thus, by the end of the century, fewer infants were being fed beikost at 1–2 mo of age than had been the case in the mid 1970s, but even at the end of the century, most infants were being fed beikost before 4 mo of age.

An unfortunate development in infant feeding in the last 20 y has been the increase in use of fruit juices. Sales of juices increased from 9.7% of beikost sales in 1971 to 16.7% in 1984 (Anderson and Ziegler 1987) and probably increased further by 1992 (Fomon 1993). As a source of nutrients, juices provide

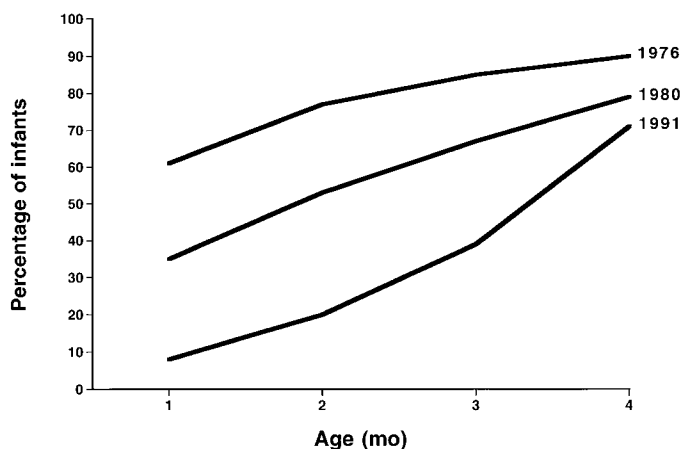


FIGURE 10 Age of introduction of infant cereal in 1976, 1980 based on Sarrett et al. (1983) and data for 1991 based on personal communication from Boettcher, J. A. (Mead Johnson Nutritionals, Evansville, IN).

primarily simple carbohydrates. Because human milk and infant formulas are rich in ascorbic acid, feeding of fruit juices cannot be justified on the basis of their contribution of ascorbic acid. Adverse reactions to consumption of juices appear to be common (Bock 1987) and regular consumption of juices by infants with erupted teeth may contribute to development of dental caries, a threat that is exaggerated because juices are marketed in bottles that accept a nipple assembly.

Delay in introduction of beikost until ~4 mo of age may have some long-term health benefit. In 1979, my colleagues and I speculated that early introduction of beikost might contribute to establishing habits of overeating (Fomon et al. 1979), and this possibility has been discussed subsequently (Committee on Nutrition 1980, Fomon 1993). The argument may be summarized as follows: Among the more important goals of nutritional management during infancy is the establishment of sound eating habits, including the habit of eating in moderation. Establishment of such habits may require that the infant be encouraged to discontinue eating at the earliest sign of willingness to do so. The infant's willingness to discontinue eating can be readily detected by an alert individual who is feeding the infant by breast or bottle and can also be readily detected during feeding by spoon, but only after the infant is able to sit with support and has fairly good control of head and neck muscles. This stage of neuromuscular development is reached in most infants by ~4 mo of age.

What may lie ahead

In the 1950s and 1960s, quite a number of reports were published on nutritional imprinting in rodents, and there was speculation that malnutrition per se, rather than the circumstances leading to and following it, might be the basis for subsequent cognitive impairment (Fomon 1967). In the 1970s and thereafter, an association was established between iron-deficiency anemia during the first few years of life and delayed cognitive development (de Andraca et al. 1997, Hurtado et al. 1999, Lozoff 1998, Pollitt 1997 and 1999), although it was not clear whether iron-deficiency anemia was a cause of delayed cognitive development or merely a marker for it, nor whether the delayed cognitive development was reversible. Nevertheless, interest in later consequences of malnutrition and iron-deficiency anemia undoubtedly stimulated interest in the field of nutritional imprinting during early life. During the last 20 y

of the 20th century, there was lively debate about the possible advantages of adding to infant formulas various substances found in human milk because of their possible effects on various aspects of development. Prominent among these debates have been the possibility that dietary intake of nucleotides might affect aspects of infant development (Raiten et al. 1998) and that consumption of long-chain polyunsaturated fatty acids might exert not only immediate but long-term effects on visual and cognitive development (Raiten et al. 1998). More recently, much attention has been focused on "metabolic programming" (Dauncey 1998, Lucas 1998, Roberts and McDonald 1998), on the possible roles of oligosaccharides (Kunz and Rudloff 1993, Newburg 1997) and probiotic bacteria (de Roos and Katan 2000) in promoting infant health. Recent advances in these areas are likely to serve as prologue to developments in infant nutrition and feeding in the 21st century.

LITERATURE CITED

- Abt, I. A. (1965) *Abt-Garrison History of Pediatrics* (Abt, I. A., ed.), pp. 222-259. W. B. Saunders, Philadelphia, PA.
- Adams, S. F. (1959) Use of vegetables in infant feeding through the ages. *J. Am. Diet. Assoc.* 35: 692-703.
- American Pediatric Society (1898) The American Pediatric Society's collective investigation of infantile scurvy in North America. *Arch. Pediatr.* 15: 481-500.
- Andelman, M. B. & Sered, B. R. (1966) Utilization of dietary iron by term infants. *Am. J. Dis. Child.* 111: 45-55.
- Anderson, T. A. & Ziegler, E. E. (1987) Recent trends in weaning in the United States. In: *Weaning: Why, What, and When?* (Ballabriga, A. & Rey, J., eds.), pp. 153-164. Raven Press, New York, NY.
- Bain, K. (1948) The incidence of breast feeding in hospitals in the United States. *Pediatrics* 2: 313-320.
- Beal, V. A. (1957) On the acceptance of solid foods and other food patterns of infants and children. *Pediatrics* 20: 448-456.
- Berenberg, W., Mandell, F. & Fellers, F. X. (1969) Hazards of skimmed milk, unboiled and boiled. *Pediatrics* 44: 734-737.
- Bock, S. A. (1987) Prospective appraisal of complaints of adverse reactions to foods in children during the first 3 years of life. *Pediatrics* 79: 683-688.
- Bracken, F. J. (1953) Infant feeding in the American colonies. *J. Am. Diet. Assoc.* 29: 349-358.
- Brennemann, J. (1911) A contribution to our knowledge of the etiology and nature of hard curds in infants' stools. *Am. J. Dis. Child.* 1: 341-359.
- Brennemann, J. (1912) The care of infants. *J. Am. Med. Assoc.* 59: 542-543, 623-624, 720-721, 797-798.
- Brennemann, J. (1929) The curd and the buffer in infant feeding. *J. Am. Med. Assoc.* 92: 364-366.
- Brown, M. L. & Ho, C. H. (1972) Low income groups in Hawaii. Infant and childhood feeding practices among low-income families in urban Hawaii. In: *Practices of Low-Income Families in Feeding Infants and Small Children with Particular Attention to Cultural Subgroups* (Fomon, S. J. & Anderson, T. A., eds.), pp. 91-95. U.S. Department of Health, Education, and Welfare, Rockville, MD.
- Bruck, E., Abal, G. & Aceto, T., Jr. (1968) Pathogenesis and pathophysiology of hypertonic dehydration with diarrhea. *Am. J. Dis. Child.* 115: 122-144.
- Butler, A. M. & Wolman, I. J. (1954) Trends in the early feeding of supplementary foods to infants; an analysis and discussion based on a nationwide survey. *Q. Rev. Pediatr.* 9: 63-85.
- Colle, E., Ayoub, E. & Raile, R. (1958) Hypertonic dehydration (hypernatremia): the role of feedings high in solutes. *Pediatrics* 22: 5-12.
- Committee on Nutrition, American Academy of Pediatrics (1957) Water requirement in relation to osmolar load as it applies to infant feeding. *Pediatrics* 19: 339-341.
- Committee on Nutrition, American Academy of Pediatrics (1962) Infantile scurvy and nutritional rickets in the United States. *Pediatrics* 29: 646-647.
- Committee on Nutrition, American Academy of Pediatrics (1965) Prepared infant formulas and commercial formula services. *Pediatrics* 36: 282-291.
- Committee on Nutrition, American Academy of Pediatrics (1967) Proposed changes in food and drug administration regulations concerning formula products and vitamin-mineral dietary supplements for infants. *Pediatrics* 40: 916-922.
- Committee on Nutrition, American Academy of Pediatrics (1971) Iron-fortified formulas. *Pediatrics* 47: 786.
- Committee on Nutrition, American Academy of Pediatrics (1976a) Commentary on breast-feeding and infant formulas, including proposed standards for formulas. *Pediatrics* 57: 278-285.
- Committee on Nutrition, American Academy of Pediatrics (1976b) Iron supplementation for infants. *Pediatrics* 58: 765-768.
- Committee on Nutrition, American Academy of Pediatrics (1980) On the feeding of supplemental foods to infants. *Pediatrics* 65: 1178-1181.

- Committee on Nutrition, American Academy of Pediatrics (1992) The use of whole cow's milk in infancy. *Pediatrics* 89: 1105-1109.
- Cook, J. D., Dassenko, S. A. & Whittaker, P. (1991) Calcium supplementation: effect on iron absorption. *Am. J. Clin. Nutr.* 53: 106-111.
- Cooke, R. E., Pratt, E. L. & Darrow, D. C. (1950) The metabolic response of infants to heat stress. *Yale J. Biol. Med.* 22: 227-249.
- Council on Foods (1937a) The nutritional significance of the curd tension of milk. *J. Am. Med. Assoc.* 108: 2040-2041.
- Council on Foods (1937b) Strained fruits and vegetables in the feeding of infants. *J. Am. Med. Assoc.* 108: 1259-1261.
- Darrow, D. C., Cooke, R. E. & Segar, W. E. (1954) Water and electrolyte metabolism in infants fed cow's milk mixtures during heat stress. *Pediatrics* 14: 602-617.
- Dauncey, M. J. (1997) From early nutrition and later development . . . to underlying mechanisms and optimal health. *Br. J. Nutr.* 78 (suppl. 2): S113-S123.
- de Andraca, I., Castillo, M. & Walter, T. (1997) Psychomotor development and behavior in iron-deficient anemic infants. *Nutr. Rev.* 55: 125-132.
- de Roos, V. M. & Katan, M. B. (2000) Effects of probiotic bacteria on diarrhea, lipid metabolism, and carcinogenesis: a review of papers published between 1988 and 1998. *Am. J. Clin. Nutr.* 71: 405-411.
- Elwood, P. C., Newton, D., Eakins, J. D. & Brown, D. A. (1968) Absorption of iron from bread. *Am. J. Clin. Nutr.* 21: 1162-1169.
- Epps, R. P. & Jolley, M. P. (1963) Unsupervised early feeding of solids to infants. *Med. Ann. D. C.* 32: 493-495.
- Executive Board (1956) American Academy of Pediatrics: Committee on Nutrition, Scope and Functions. *Pediatrics* 18: 159.
- Filer, L. J., Jr. (1971a) Salt in infant foods. *Nutr. Rev.* 29: 27-30.
- Filer, L. J., Jr. (1971b) Modified food starches for use in infant foods. *Nutr. Rev.* 29: 55-59.
- Fomon, S. J. (1967) *Infant Nutrition*, pp. 211, 276. W. B. Saunders, Philadelphia, PA.
- Fomon, S. J. (1974) *Infant Nutrition*, 2nd ed., p. 80. W. B. Saunders, Philadelphia, PA.
- Fomon, S. J. (1975) What are infants fed in the United States? *Pediatrics* 56: 350-355.
- Fomon, S. J. (1987a) Bioavailability of supplemental iron in commercially prepared dry infant cereals. *J. Pediatr.* 110: 660-661.
- Fomon, S. J. (1987b) Reflections on infant feeding in the 1970s and 1980s. *Am. J. Clin. Nutr.* 46: 171-182.
- Fomon, S. J. (1993) *Nutrition of Normal Infants*. W. B. Saunders, St. Louis, MO.
- Fomon, S. J., Filer, L. J., Jr., Anderson, T. A. & Ziegler, E. E. (1979) Recommendations for feeding normal infants. *Pediatrics* 63: 52-59.
- Fomon, S. J., Filer, L. J., Jr., Ziegler, E. E., Bergmann, K. E. & Bergmann, R. L. (1977) Skim milk in infant feeding. *Acta Paediatr. Scand.* 66: 17-30.
- Fomon, S. J., Sanders, K. D. & Ziegler, E. E. (1990) Formulas for older infants. *J. Pediatr.* 116: 690-696.
- Fomon, S. J. & Ziegler, E. E. (1999) Renal solute load and potential renal solute load in infancy. *J. Pediatr.* 134: 11-14.
- Fomon, S. J., Ziegler, E. E., Nelson, S. E. & Edwards, B. B. (1981) Cow milk feeding in infancy: gastrointestinal blood loss and iron nutritional status. *J. Pediatr.* 98: 540-545.
- Food and Drug Administration (1971) Rules and regulations. Label statements concerning dietary properties of food purporting to be or represented for specific dietary uses. *Fed. Regist.* 36: 23553-23556.
- Food and Drug Administration (1985) Rules and regulations. Nutrient requirements for infant formulas. *Fed. Regist.* 50: 45106-45108.
- Forbes, G. B. & Woodruff, C. W. (1985) *Pediatric Nutrition Handbook*, 2nd ed. (Forbes, G. B. & Woodruff, C. W., eds.), pp. 364-366. American Academy of Pediatrics, Elk Grove Village, IL.
- Forsyth, D. (1910-1911) The history of infant feeding from Elizabethan times. *Proc. R. Soc. Med.* 4: 110-141.
- Friedenwald, J. & Ruhrah, J. (1905) *Diet and Health in Disease*, pp. 200, 204. W. B. Saunders, Philadelphia, PA.
- Funk, C. (1912) The etiology of the deficiency diseases. *J. State Med.* 20: 341-368.
- Gerstenberger, H. J., Haskins, H. D., McGregor, H. H. & Ruh, H. O. (1915) Studies in the adaptation of an artificial food to human milk. *Am. J. Dis. Child.* 10: 249-265.
- Gulee, C. G., Sanford, H. N. & Herron, P. H. (1934) Breast and artificial feeding. Influence on morbidity and mortality of twenty thousand infants. *J. Am. Med. Assoc.* 103: 735-738.
- Hallberg, L., Brune, M., Erlandsson, M., Sandberg, A.-S. & Rossander-Huttén, L. (1991) Calcium: effect of different amounts on nonheme- and heme-iron absorption in humans. *Am. J. Clin. Nutr.* 53: 112-119.
- Harris, L. E. & Chan, J.C.M. (1969) Infant feeding practices. *Am. J. Dis. Child.* 117: 483-491.
- Hirschman, C. & Butler, M. (1981) Trends and differentials in breast feeding: an update. *Demography* 18: 39-54.
- Hirschman, C. & Hendershot, G. E. (1979) Trends in breast feeding among American mothers. *Vital and Health Statistics Series 23*, no. 3. Department of Health, Education, and Welfare, Hyattsville, MD.
- Holt, L. E., Jr. (1963) Let us give the Russians their due [letter]. *Pediatrics* 32: 462.
- Hopkins, F. G. (1906) The analyst and the medical man. *Analyst* 31: 385-404.
- Hurrell, R. F. (1984) Bioavailability of different iron compounds used to fortify formulas and cereals: technological problems. In: *Iron Nutrition in Infancy and Childhood* (Stekel, A., ed.), pp. 147-176. Raven Press, New York, NY.
- Hurrell, R. F., Furnniss, D. E., Burri, J. & Whittaker, P. (1989a) Iron fortification of infant cereals: a proposal for the use of ferrous fumarate or ferrous succinate. *Am. J. Clin. Nutr.* 49: 1274-1282.
- Hurrell, R. F., Lynch, S. R., Trinidad, T. P., Dassenko, S. A. & Cook, J. D. (1989b) Iron absorption in humans as influenced by bovine milk proteins. *Am. J. Clin. Nutr.* 49: 546-552.
- Hurtado, E. K., Claussen, A. H. & Scott, K. G. (1999) Early childhood anemia and mild or moderate mental retardation. *Am. J. Clin. Nutr.* 69: 115-119.
- Jerome, N. W., Kiser, B. B. & West, E. A. (1972) Infant and child feeding practices in an urban community in the north-central region. In: *Practices of Low-Income Families in Feeding Infants and Small Children with Particular Attention to Cultural Subgroups* (Fomon, S. J. & Anderson T. A. eds.), pp. 49-56. U.S. Dept. of Health, Education, and Welfare, Rockville, MD.
- Joseph, S. C. (1981) The anatomy of the infant formula controversy. *Am. J. Dis. Child.* 135: 889-892.
- Kunz, C. & Rudloff, S. (1993) Biologic functions of oligosaccharides in human milk. *Acta Paediatr.* 82: 903-912.
- Looker, A. C., Dallman, P. R., Carroll, M. S., Gunter, E. W. & Johnson, C. L. (1997) Prevalence of iron deficiency in the United States. *J. Am. Med. Assoc.* 277: 973-976.
- Lozoff, B. (1998) Explanatory mechanisms for poorer development in iron-deficient anemic infants. In: *Nutrition, Health and Child Development*. Pan American Health Organization, The World Bank, and Tropical Metabolism Research Unit, Scientific Publication 566: 162-178.
- Lucas, A. (1998) Programming by early nutrition: an experimental approach. *J. Nutr.* 128: 401S-406S.
- Marriott, M. (1927) Preparation of lactic acid milk mixtures for infant feeding. *J. Am. Med. Assoc.* 89: 862-863.
- Marriott, W. M. (1935) *Infant Nutrition; A Textbook of Infant Feeding for Students and Practitioners of Medicine*, 2nd ed., p. 149. The C.V. Mosby Company, St. Louis, MO.
- Marriott, W. M. & Davidson, L. T. (1923) Acidified whole milk as a routine infant food. *J. Am. Med. Assoc.* 81: 2007-2009.
- Marriott, M. & Schoenthal, L. (1929) An experimental study of the use of unsweetened evaporated milk for the preparation of infant feeding formulas. *Arch. Pediatr.* 46: 135-148.
- Martinez, G. A., Dodd, D. A. & Samartgedes, J. (1981) Milk feeding patterns in the United State during the first 12 months of life. *Pediatrics* 68: 863-868.
- Martinez, G. A. & Krieger, F. W. (1985) 1984 Milk-feeding patterns in the United States. *Pediatrics* 76: 1004-1008.
- McCollum, E. V. (1957) *A History of Nutrition. The Sequence of Ideas in Nutrition Investigations* (Glass, H. B., ed.), pp. 190, 201-228, 259, 281. Houghton Mifflin, Boston, MA.
- McComas, M. (1988) Origins of the controversy. In: *Infant Feeding. Anatomy of a Controversy 1973-1984* (Dobbing, J., ed.), pp. 29-41. Springer-Verlag, Berlin, Germany.
- Mellanby, E. (1920) Accessory food factors (vitamines) in the feeding of infants. *The Lancet* i: 856-862.
- Miller, S. A. (1989) Problems associated with the establishment of maximum nutrient limits in infant formula. *J. Nutr.* 119: 1764-1767.
- Morse, J. L. (1935) Recollections and reflections on forty-five years of artificial infant feeding. *J. Pediatr.* 7: 303-324.
- Nelson, S. E., Ziegler, E. E., Copeland, A. M., Edwards, B. B. & Fomon, S. J. (1988) Lack of adverse reactions to iron-fortified formula. *Pediatrics* 81: 360-364.
- Newburg, D. S. (1997) Do the binding properties of oligosaccharides in milk protect human infants from gastrointestinal bacteria? *J. Nutr.* 127: 980S-984S.
- Oski, F. A. (1980) Iron-fortified formulas and gastrointestinal symptoms in infants: a controlled study. *Pediatrics* 66: 168-170.
- Owen, G. M., Kram, K. M., Garry, P. J., Lowe, J. E. & Lubin, A. H. (1974) A study of nutritional status of preschool children in the United States, 1968-1970. *Pediatrics* 53: 597-646.
- Pilch, S. M. & Senti, F. R. (1984) Assessment of iron nutritional status of the U.S. population based on data in the Second Health and Nutrition Examination Survey, 1976-1980. Life Science Research Office, Federation of American Societies for Experimental Biology, Bethesda, MD.
- Pollitt, E. (1997) Iron deficiency and educational deficiency. *Nutr. Rev.* 55: 133-140.
- Pollitt, E. (1999) Early iron deficiency and later mental retardation. *Am. J. Clin. Nutr.* 69: 4-5.
- Powers, G. F. (1935) Infant feeding. Historical background and modern practice. *J. Am. Med. Assoc.* 105: 753-761.
- Pratt, E. L., Bienvu, B. & Whyte, M. M. (1948) Concentration of urine solutes by young infants. *Pediatrics* 1: 181-187.
- Raiten, D. J., Talbot, J. M. & Waters, J. H. (1998) Assessment of nutrient requirements for infant formulas. *J. Nutr.* 128 (suppl.): 2059S-2293S.
- Randall, B., Bartlet, S. & Kennedy, S. (1998) Study of WIC Participant and Program Characteristics 1996. U.S. Department of Agriculture, Food and Nutrition Service, Alexandria, VA. (FNS 53-3198-3-026).
- Richman, L., Hildebaugh, T., Ku, L., McMahon-Cox, N., Dayton, C. M. & Goodrich, N. (1986) Final Report: Study of WIC Program and Participant

- Characteristics. U.S. Department of Agriculture, Food and Nutrition Service, Alexandria, VA. (Contract # 53-3198-3-135).
- Rios, E., Hunter, R. E., Cook, J. D., Smith, N. J. & Finch, C. A. (1975) The absorption of iron as supplements in infant cereal and infant formulas. *Pediatrics* 55: 686-693.
- Roberts, S. B. & McDonald, R. (1998) The evolution of a new research field: metabolic programming by early nutrition. *J. Nutr.* 128: 400S.
- Rosen, G. (1958) *A History of Public Health*, pp. 351-360. M.D. Publications, New York, NY.
- Rotch, T. M. (1907) An historical sketch of the development of percentage feeding. *N. Y. Med. J.* 85: 532-537.
- Rubner, M. & Heubner, O. (1899) Die künstliche Ernährung eines normalen und eines atrophischen Säuglings. *Z. Biol.* 38: 315-398.
- Sackett, W. W. (1953) Results of three years experience with a new concept of baby feeding. *South. Med. J.* 46: 358-363.
- Sarrett, H. P., Bain, K. R. & O'Leary, J. C. (1983) Decisions on breast-feeding or formula feeding and trends in infant-feeding practices. *Am. J. Dis. Child.* 137: 719-725.
- Setchell, K.D.R., Zimmer-Nechemias, L., Cai, J. & Heubi, J. E. (1997) Exposure of infants to phyto-estrogens from soy-based infant formulas. *Lancet* 350: 23-27.
- Singer, J. D., Granahan, P. & Goodrich, N. N. (1982) Diet and iron status. A study in relationships; United States, 1976-1980. *Vital and Health Statistics Series 11*, no. 229. U.S. Government Printing Office, Washington, DC.
- Smith, E. (1885) *On the Wasting Diseases of Infants and Children*. pp. 29-31. William Wood, New York, NY.
- Stewart, C. P. & Guthrie, P., eds. (1953) *Lind's treatise on scurvy. A bicentenary volume containing reprint on the first edition of a treatise of the scurvy*, by James Lind, M.D. with additional notes, p. 314. Edinburgh University Press, Edinburgh, Scotland.
- Valentine, B. L. & Valentine, C. A. (1972) Poor people, good food, and fat babies: observations on dietary behavior and nutrition among low-income, urban Afro-American infants and children. In: *Practices of Low-Income Families in Feeding Infants and Small Children with Particular Attention to Cultural Subgroups* (Fomon, S. J. & Anderson, T.A., eds.), pp. 59-65. U.S. Department of Health, Education, and Welfare, Rockville, MD.
- Wharton, C. R. (1941) *Gail Borden, Pioneer*, p. 193. The Naylor Company, San Antonio, TX.
- Yankauer, A. (1994) A classic study of infant mortality—1911-1915. *Pediatrics* 94: 874-877.
- Ziegler, E. E., Fomon, S. J., Nelson, S. E., Rebouche, C. J., Edwards, B. B., Rogers, R. R. & Lehman, L. J. (1990) Cow milk feeding in infancy: further observations on blood loss from the gastrointestinal tract. *J. Pediatr.* 116: 11-18.