Dietary Zinc and Iron Sources, Physical Growth and Cognitive Development of Breastfed Infants

Nancy F. Krebs

Section of Nutrition, Department of Pediatrics, University of Colorado School of Medicine, Denver, CO 80262

ABSTRACT Iron and zinc are trace minerals that are of critical importance to the young infant for normal growth and development. Nutritional requirements, including those for both of these micronutrients, are generally met for term infants by exclusive feeding of human milk for about the first 6 mo of life. Introduction and selection of complementary foods then become important, in addition to breastfeeding, to meet the nutritional needs of infants. The objectives of this paper are to review iron and zinc requirements in late infancy; to review current practices with respect to initiation of complementary feeding; and to review briefly studies that examine the effects of different choices of complementary foods on iron and zinc status. Results of these studies, although requiring further verification, suggest that increased meat intake by breastfed infants >6 mo old would adequately support both iron and zinc requirements. J. Nutr. 130: 358S–360S, 2000.

KEY WORDS: • iron • zinc • breastfed infants • complementary foods

Iron and zinc are critical for normal growth, hematopoiesis and neurologic development during infancy. Nutritional requirements, including those for both of these micronutrients, are generally met for term infants by exclusive feeding of human milk for about the first 6 mo of life. Introduction and selection of complementary foods then become important, in addition to breastfeeding, to meet the nutritional needs of infants. The objectives of this paper are to review iron and zinc requirements in late infancy; to review current practices with respect to initiation of complementary feeding; and to review briefly studies that examine the effects of different choices of complementary foods on iron and zinc status of older infants.

An important consideration for meeting iron requirements in early infancy is the contribution of human milk. The iron concentration of iron in human milk is relatively low, 0.2–0.4 mg/L, and concentrations decline only modestly over the course of lactation. The efficiency of absorption of iron from human milk is quite high, averaging ~50% (Dallman 1988). Total body iron is relatively stable from birth through ~4 mo of age, but the distribution changes somewhat as stores are utilized to support growth. Between 4 and 12 mo, there is a substantial increase in the erythrocyte mass, and to a lesser extent, in the myoglobin in lean tissue (Dallman 1988). This increase in iron requirements between 4 and 12 mo cannot be met readily by the iron available from human milk, and other sources of dietary iron become increasingly important by midway through y 1 of life (Institute of Medicine 1993).

The young infant has a relatively high zinc requirement to support the very rapid growth of early infancy. Milk zinc concentrations are quite high in the early weeks postpartum, averaging >3 mg/L at 2 wk, but then decline sharply over the early weeks of lactation (Krebs et al. 1995). Although the zinc concentrations in well-nourished women are relatively resistant to changes in maternal zinc intake, considerable variability in milk zinc concentrations exists among women. There is also quite strong “tracking” of concentrations, with significant correlation between concentrations in early (2 wk postpartum) and mature milk (5–7 mo) (Krebs et al. 1995). Despite increases in volume of milk intake over the early weeks postpartum, the steep decline in milk zinc concentrations results in a longitudinal decline in zinc intake as well (Krebs et al. 1994) (Fig. 1). As shown in the figure, factorial estimates of longitudinal requirements for net absorption of zinc also are highest in the early weeks of life (Krebs and Hambidge 1986). The gap between intake and requirement narrows considerably between 2 wk and 5 mo of age; by 7 mo, the intake from human milk is nearly equal to estimated requirements for net absorption (Fig. 1). In such circumstances, the efficiency of absorption would have to be close to 100% to meet estimated requirements (Krebs and Hambidge 1986).
were consuming cereals and fruits, but less than half were of the infants at 6 mo. By 1 yo of age, over half of the infants considerably fewer taking fruits. Meats were not consumed by any the greatest number, followed closely by vegetables, with con-

100 infants studied at 6 mo of age, cereals were consumed by have been examined recently (Skinner et al. 1997). Of nearly iron-fortified cereal (especially concurrently with a source of nutrients, all of which may become limiting in the older breastfed infant. As noted above, iron and zinc are prime examples. Infants’ natural preference for sweet taste results in ready acceptance of fruits as an early complementary food (Beauchamp and Moran 1982). Other foods, which may have more nutritional relevance, are less readily accepted. In combination with neophobia, fear of new things, this often gives parents the impression that the initial rejection indicates a dislike of a particular food (Birch and Grimm-Thomas 1996).

Consideration of past patterns of introduction of complementary foods indicates an extremely wide range of practice (Fomon 1993). For centuries, cereal gruels have been commonly introduced to very young infants. In the early part of this century, beef broth and meats were fed within 1 y of life, but green vegetables were withheld until nearly 3 y of age. One of the most radical sets of recommendations were those in the 1950s that promoted introduction of foods from all major food groups by 3 wk of age (Fomon 1993). Currently, the American Academy of Pediatrics (AAP) recommends that introduction of solids be delayed for breastfed infants until ~6 mo of age (American Academy of Pediatrics 1997). Additional infant feeding guidelines from the AAP also note that, if complementary foods are withheld until ~6 mo of age, the order of introduction of specific foods is not critical (American Academy of Pediatrics 1998). In a report on meeting iron needs during infancy, the Institute of Medicine recommended introduction of solids by 4–6 mo. That report suggested that iron needs of the infant can be met either by introduction of iron-fortified cereal (especially concurrently with a source of vitamin C) or by introduction of meat at this age (Institute of Medicine 1993).

Current practices for introduction of complementary foods have been examined recently (Skinner et al. 1997). Of nearly 100 infants studied at 6 mo of age, cereals were consumed by the greatest number, followed closely by vegetables, with considerably fewer taking fruits. Meats were not consumed by any of the infants at 6 mo. By 1 y of age, over half of the infants were consuming cereals and fruits, but less than half were reported to be consuming meat or meat mixtures. Only 10% of the infants consumed beef at 12 mo. The authors commented on the striking popularity and frequency with which certain foods were consumed at 12 and 16 mo: “bananas, toasted oat cereal, cheese, chicken, crackers, potatoes and yogurt.” These observations suggest that, as recommended, iron-fortified cereals were consumed as an early complementary food, and likely contributed importantly to meeting infants’ iron needs. The calculated nutrient intakes between 6 and 12 mo equaled or exceeded the Recommended Dietary Allowance (RDA) for iron and most other micronutrients, but with zinc as a notable exception. Between 12 and 24 mo, mean zinc intake was estimated consistently at 50–60% of the RDA (NRC 1989, Skinner et al. 1997).

The nutritional implications of different choices of complementary foods are quite striking. The protein, iron and zinc content of fruits, iron-fortified rice cereal, beef and poultry are shown in Figure 2 (Pennington 1989). Although fruits are commonly introduced as an early “solid,” they contribute very little protein, iron or zinc; they do provide fiber and certain vitamins. Iron-fortified infant cereals obviously contribute substantial amounts of iron. Beef and chicken contribute several-fold more protein, moderately more zinc and much less iron, compared with the cereal. It can also be seen from the figure that although both meat and poultry are good sources of protein, beef is considerably higher than chicken in zinc and approximately equivalent in iron (Pennington 1989).

Several studies have evaluated the effects of complementary foods on iron and zinc status of infants. In a longitudinal study from Denmark in which infants were followed from birth to 12 mo, iron status was examined in relation to feeding patterns. Between 6 and 9 mo of age, serum ferritin was negatively associated with intakes of bread and cow’s milk. There was a trend for positive association between serum ferritin and intakes of meat and fish (Michaelsen et al. 1995).

An intervention study examined the effect of greater intake of meat as a complementary food (Engelmann et al. 1998b). In this study, 8-mo-old partially breastfed infants were randomly assigned to either a low (10 g/d) or high (27 g/d) meat groups for a 2-mo intervention period. The meat puree contained beef, lamb, poultry or fish; the remainder of energy intake (milk, cereal, bread, fruit) was chosen freely by parents. Iron-fortified formula intake and iron-fortified gruels were not controlled. The results after the intervention indicated that protein and iron intakes were greater in the high meat group. Total iron and zinc intakes were not significantly different between groups, a finding attributed to the low meat group having consumed more iron-fortified gruel, breads and cereals.

![FIGURE 1](https://academic.oup.com/jn/article-abstract/130/2/358S/4686412)

**FIGURE 1** Longitudinal zinc intakes from human milk by exclusively breastfed infants, based on 72-h test weighing (Krebs et al. 1994). Values are means ± SEM. Lower line indicates calculated requirements by factorial method for net absorption of zinc by infants (Krebs and Hambidge 1986).

![FIGURE 2](https://academic.oup.com/jn/article-abstract/130/2/358S/4686412)

**FIGURE 2** Comparison of protein, iron and zinc contents of selected complementary foods (Pennington 1989).
Comparison of biochemical indices of iron and zinc status at the end of the intervention indicated that for those in the low meat group, hemoglobin declined significantly, whereas for the "high" meat group, hemoglobin was minimally lower. There were no differences in ferritin or plasma zinc between the two groups. Given that intakes of iron were not different, the authors concluded that the iron in meat was better absorbed and resulted in improved hematologic status (Engelmann et al. 1998b).

These investigators also examined the effect of the addition of meat on nonheme iron absorption from a vegetable puree in a subgroup of 10-mo-old infants. Iron absorption was studied by iron stable isotope incorporation into erythrocytes. Nonheme iron absorption was significantly higher from the vegetable puree containing meat; addition of 25 g meat to 100 g vegetable puree led to a 2.7-fold increase in total iron absorbed. The amount of iron absorbed from the meat-enriched vegetable puree was ~30% of the daily iron requirement; the amount of iron absorbed from the vegetable puree was ~12% of the daily iron requirement. No significant correlations between nonheme iron absorption and other outcome measures were found, although the small number of subjects in the absorption studies may have precluded detection of such relationships (Engelmann et al. 1998a).

We have taken a somewhat different approach to testing the effects of introduction of meat into infants' diets. We examined the effects of beef vs. iron-fortified cereal as first complementary food on growth, zinc and iron status, development and absorption of zinc. Subjects included exclusively breastfed infants, enrolled at 3–4 mo of age, who were randomly assigned to either pureed beef or iron-fortified rice cereal as a first complementary food, to be introduced between 5 and 7 mo. Intake of the other test food was not allowed until after 7 mo, but no restrictions were placed on intake of foods low in iron and zinc, such as pureed fruits and vegetables. The infants were followed through 1 y of age.

The intervention resulted in significantly higher dietary intakes of protein and zinc in the beef group from 5 through 7 mo, but these differences disappeared at the 9- and 12-mo follow-ups. Iron intake was significantly higher in the cereal group at 7 mo, but also was not different thereafter. The mothers were also asked to record during each diet record period the baby's “acceptance” of the assigned food. There was no difference between the cereal and beef groups with respect to acceptance. No effect of the intervention was found on growth, development or biochemical indices of iron and zinc status at 9 mo (Westcott et al. 1998).

Zinc absorption studies were undertaken in a subset of infants at 7 mo of age. For these studies, we administered zinc stable isotopes on two consecutive days, one with the assigned complementary food alone (beef or cereal), and on the following day with the assigned complementary food plus human milk. Although fractional absorption of zinc was slightly higher in the beef group than in the cereal group, the difference was not significant. Absorption for both groups averaged ~40%. Comparison of zinc intake from the test meal and the amount absorbed (intake × fraction absorption) yielded significantly greater absorbed zinc from the beef test meal compared with the cereal meal (P = 0.001). Had the differences in intake of zinc persisted beyond 7 mo, it seems likely that the enhanced quantity of intake of a highly bioavailable source of zinc would result in improved zinc status. This tentative conclusion is based on the measurement of the exchangeable zinc pool, which was correlated with zinc intake (P < 0.05) (Jalla et al. 1998).

In summary, these investigations found no difference in acceptance by breastfed infants of meat, including pureed beef, compared with other complementary foods (Engelmann et al. 1998b, Westcott et al. 1998). This is consistent with research that indicates that repeated exposure to new foods, especially those that are not sweet, is critical for acceptance (Birch and Grimm-Thomas 1996). Intake of meat was associated with higher intakes of protein and zinc, but without an effect on energy intake from complementary foods (Westcott et al. 1998). Intake of meat is associated with enhanced absorption of nonheme iron (Engelmann et al. 1998a). Although zinc absorption was not significantly greater in beef compared with cereal, the greater zinc content of the meat resulted in significantly more absorbed zinc from beef (Jalla et al. 1998). Meat intake was associated with hematological status that was at least equivalent (Westcott et al. 1998), or possibly improved (Engelmann et al. 1998b), and with equivalent growth and development (Westcott et al. 1998). These surveillance and intervention studies were undertaken in populations of infants from low-income homes and in relatively protected environments. It was thus likely that food availability and knowledge of appropriate feeding practices were favorable. Such may not be the same for more marginalized environments, particularly those with more infectious morbidity and less choice in complementary foods. These results suggest that introducing meat products as a component of the diet may benefit the micronutrient status of the weaning infant in such environments.

LITERATURE CITED


