Approaches to Improve Iron Bioavailability from Complementary Foods

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ABSTRACT The importance of trace element bioavailability in the etiology of nutritional deficiencies, for example in the etiology of iron deficiency and iron deficiency anemia, can be expected to be most pronounced in individuals with high requirements. Of special concern is the situation in poor communities where infants and young children are consuming monotonous, cereal-based diets. Traditionally, cereal-based gruels are often one of the first semisolids foods to be introduced into the infant’s diet. These foods can be expected to have low energy and nutrient density as well as low bioavailability of iron due to the presence of phytic acid. Ascorbic acid is a potent enhancer of non-heme iron absorption that can overcome the inhibiting effect of phytic acid when present in high enough quantities. However, home prepared complementary foods based on cereals and legumes contain negligible amounts of ascorbic acid unless ascorbic acid-rich foods are mixed with the cereal or consumed at the same time. Different approaches to improve iron bioavailability from plant-based complementary foods, e.g., by enzymatic degradation of phytic acid and/or by increased consumption of ascorbic acid-rich foods, should be explored and adapted to local conditions. In addition, there is a need to evaluate efficacy and effectiveness of strategies to increase the dietary intake of bioavailable iron by dietary diversification and food fortification under realistic conditions. J. Nutr. 133: 1560S–1562S, 2003.

KEY WORDS: • bioavailability • iron • infants

The transition from exclusive breastfeeding to family foods represents a phase in life when infants are very vulnerable nutritionally. The gradual change to energy and nutrients provided by semisolids foods, at the expense of human milk, requires access to appropriate complementary foods with high energy and nutrient density as well as high nutrient bioavailability. This review is focused on the importance of adequate iron bioavailability from the diet during early life and includes a discussion about different food-based approaches to improve iron nutrition in infants and young children.

The iron content of human milk is very low and iron bioavailability (measured as erythrocyte incorporation of iron stable isotopes) has also been demonstrated to be low, with a geometric mean of 11.8%, and similar to that of low-iron infant formula (1, 2). However, full-term breast-fed infants generally have adequate iron status during the first 4–6 mo of life, but after this time, when iron stores have been depleted, additional dietary iron needs to be supplied for the rapidly expanding blood volume and replacement of iron losses (3). The World Health Organization (WHO) recommends introduction of complementary foods, in addition to human milk, at 6 mo of age (4). The recent review “The optimal duration of exclusive breast-feeding” (5) concludes that, although data are scarce, exclusive breastfeeding for 6 mo without iron supplementation may compromise the hematological status of infants in developing countries. Of special concern is the situation in low-birth-weight (<2500 g) infants who are born with very limited storage iron, and double their birth weight in a shorter time than term infants, and are therefore at higher risk for development of iron deficiency (3). It is important to note that the prevalence of low-birth-weight infants is high in many developing countries (6). The impact of birth weight on estimated requirements of absorbed iron during the first year of life is illustrated by Fomon (7): 0.55 mg absorbed iron/d for infants with a birth weight of 3.5 kg (and an estimated body weight of 10.5 kg at 1 y) and 0.75 mg absorbed iron/d for infants with a birth weight of 2.5 kg (estimated body weight 10 kg at 1 y). These values correspond to daily dietary intakes of iron in the range 5.5–11 mg (for infants with a birth weight of 3.5 kg) and 7.7–15 mg (for infants with a birth weight of 2.5 kg), assuming 10% and 5% iron bioavailability, respectively. These estimates highlight the importance of access to appropriate...
complementary foods with adequate iron content and of optimizing iron bioavailability during early life to prevent the development of iron deficiency and iron deficiency anemia (IDA). The adverse effects of IDA during infancy on child development were recently reviewed (8) and will not be discussed in this paper.

Iron bioavailability: the effect of phytic acid

Traditionally, cereal-based gruels are often one of the first semisolid foods to be introduced into the infant’s diet. In resource-poor areas where high extraction-cereal flours are more readily available, and affordable, than refined cereal flours and vegetable proteins are added instead of cow milk to improve protein quality, the cereal mixtures often contain relatively high amounts of the strong metal chelator phytic acid (myo-inositol-hexa-phosphate). Iron bioavailability from cereal products is typically low due to the presence of phytic acid (9), however, phytic acid can be degraded by activating native phytase or by the addition of exogenous phytase. The industrially produced dephytinized infant foods discussed in this review were prepared by the addition of exogenous phytase. In addition, we have recently demonstrated the usefulness of whole grain cereals as sources of phytase for production of complementary foods based on cereals and legumes (10,11).

The strong inhibitory effect of phytic acid on iron bioavailability in infants was first demonstrated in a study where soy formulas were evaluated before and after dephtyatinization. The geometric mean bioavailability of iron increased from 5.5% to 6.8% ($p < 0.05$) after degradation of 83% phytic acid, whereas a more pronounced effect was shown after 100% dephtyatinization; the geometric mean increased from 3.9% to 8.7% ($p < 0.001$) (12). However, dephtyatinization of a soy isolate with relatively low native phytic acid content did not increase iron bioavailability from infant formula significantly (13), and no difference in iron bioavailability was observed between two cereal products based on low extraction-wheat flour and cow milk before (0.08% phytic acid) and after dephtyatinization (0.01% phytic acid) (14). The lack of effect of dephtyatinization of infant foods with relatively low native phytic acid content on iron bioavailability (13,14) can probably be attributed to the relatively high content of ascorbic acid in the test meals that counteracted the inhibitory effect of phytic acid.

Iron bioavailability: the effect of ascorbic acid

Ascorbic acid is a potent enhancer of iron absorption that can overcome the inhibiting effect of phytic acid when present in high enough quantities. For example, iron bioavailability from soy infant formula was enhanced to the same extent by dephtyatinization or by increasing the molar ratio of ascorbic acid (176 g/mol) from 2.1 to 4.2 [relative to iron (56 g/mol)] in the formula containing native phytic acid (12). Ascorbic acid added to the wheat- and cow milk-based infant cereal mentioned earlier (14) at a molar ratio of 2:1 (ascorbic acid:iron) resulted in relatively high iron bioavailability from both the phytic acid-containing infant cereal and the dephtyatinized product. In our earlier study with infant cereals based on high extraction wheat flour and soy flour (15), the level of phytic acid was much higher (0.77% and 0.30%, respectively) and bioavailability of iron was low even though approximately the same amount of ascorbic acid was added as in the later study. Thus, the ability of ascorbic acid to overcome the inhibitory effect of phytic acid depends both on the level of phytic acid in the food and on the amount of ascorbic acid present.

Home prepared complementary foods based on cereals and legumes consumed by infants in developing countries can be assumed to contain relatively high amounts of phytic acid and negligible amounts of ascorbic acid unless ascorbic acid-rich foods such as fruit, fruit juice or vegetables are mixed with the cereal or consumed at the same time. The inclusion of ascorbic acid-rich fruits or vegetables into the diets of infants and young children depends on availability, affordability, tradition and other factors. For example, our recent data from Côte d’Ivoire clearly demonstrated that fruit and fruit juice were rarely included in the diet of children 6–18 mo old in Abidjan (16).

Strategies to improve iron nutrition

Different approaches to improve iron bioavailability from plant-based complementary foods, e.g., by enzymatic degradation of phytic acid and by increased consumption of ascorbic acid-rich fruits and vegetables, should be explored and adapted to local conditions. In addition, the possibility of introducing foods with high iron content/high bioavailability into the diet should be evaluated. For example, meat, in particular red meat, is an excellent source of highly bioavailable heme iron. In addition, the inclusion of beef significantly increased non-heme iron bioavailability from a vegetable-based meal in infants (17).

Furthermore, novel strategies to increase the dietary intake of bioavailable iron by food fortification need to be developed. To establish a food fortification program, several important factors need to be considered; the choice of the food vehicle and iron compound, the fortification level and ways to enhance iron bioavailability from the fortified food. For example, industrially produced infant formulas are usually fortified with highly bioavailable water-soluble iron compounds, such as ferrous sulfate, and contain added ascorbic acid. However, cereal products are difficult to fortify with water-soluble iron compounds due to unacceptable organoleptic changes (rancidity, flavor/color changes) during storage and/or during food preparation. Consequently, less soluble, and therefore less bioavailable, iron compounds such as elemental iron powders and ferric pyrophosphate are commonly used to fortify cereal products. Alternative compounds, for example ferrous fumarate, which are poorly soluble in water but soluble in dilute acid such as the gastric juice, have been shown to cause less unacceptable organoleptic changes in the fortified food during storage and have similar bioavailability as ferrous sulfate in healthy adults (for a review, please see reference 18). Very limited information is available on iron bioavailability from compounds that dissolve slowly or incompletely in the gastric juice, as these compounds must be intrinsically labeled with stable isotopes of iron before testing in infants and children. For example, a study in European infants demonstrated that ferrous fumarate was significantly more bioavailable than ferric pyrophosphate when added to an infant cereal (molar ratio of 3:1, ascorbic acid relative to iron); geometric mean iron bioavailability was 4.1% versus 1.3% (19). Iron bioavailability from ferrous fumarate has not been compared directly to ferrous sulfate in Western infants or young children. However, a recent study reported relative bioavailability of ferrous fumarate to be about 30% in 2- to 5-y-old Bangladeshi children from an infant cereal (molar ratio of 3:1, ascorbic acid relative to iron) (20). These results indicate that the impact of iron fortification programs using nonwater soluble iron compounds such as ferrous fumarate should be carefully evaluated in young children.

CONCLUSION

Effective strategies to combat the most prevalent micronutrient deficiency in the world, iron deficiency, are urgently
needed, in particular for infants and young children in developing countries. Efficacy and effectiveness of different approaches to improve iron content and iron bioavailability from complementary foods, by food fortification and dietary diversification, need to be evaluated under realistic conditions. A large proportion of infants and young children in many settings do not have access to industrially produced foods, and traditional food fortification programs are therefore not an option. Novel approaches need to be explored, for example the possibility of fortifying complementary foods at the household level. In addition, the possibilities of degrading phytic acid in cereal-based complementary foods and increasing consumption of foods rich in ascorbic acid to counteract the inhibitory effect of phytic acid should be explored and adapted to local conditions. The importance of animal products in the diet, in particular the inclusion of small, realistic amounts of meat into plant-based diets to improve iron status in infants and children, needs to be evaluated.

LITERATURE CITED


