www.jpeds.com • THE JOURNAL OF PEDIATRICS

# A Substantial Proportion of 6- to 12-Month-Old Infants Have Calculated Daily Absorbed Iron below Recommendations, Especially Those Who Are Breastfed

Steven A. Abrams, MD[1], Joel C. Hampton, MS[2], and Kristen L. Finn, DCN, RD[3]

**Objective** To calculate the amount of bioavailable iron consumed among 6- to 12- month-old infants considering differences in iron bioavailability among dietary iron sources and to compare this with current recommended intakes.

**Study design** We used the Feeding Infants and Toddlers Study database of dietary intakes from 2016 and the estimated bioavailability of dietary iron sources to evaluate the proportion of infants whose calculated total daily absorbed iron fell below physiologic requirements, that is, the recommended amount needed to fully support growth and erythropoiesis.

**Results** The calculated daily iron absorption was below the recommended amount in 54.3% of infants evaluated ranging from 19.5% of 448 exclusively formula-fed infants, to 95.8% of 296 exclusively breastfed infants and 72.2% of 102 mixed fed infants. The calculated mean iron absorption of 6- to 9- month-old breastfed infants was 0.27 mg/day, far less than the estimated physiologic requirement of 0.69 mg/day. The most highly bioavailable iron, heme iron, was <12% of the contributor to total iron absorbed in breastfed infants.

**Conclusions** These data indicate a need for further education and public health policies to support increased iron intake in 6- to 12- month-old infants, emphasizing those receiving any breast milk. Exclusively formula-fed infants are at lower risk, but rates of low absorbed iron indicate that all infants may need monitoring for clinical evidence of low iron status. Consideration should be given to increasing the proportion of heme iron obtained from animal products in the diet where feasible. *(J Pediatr 2021;231:36-42)*.

See editorial, p 34

Iron deficiency remains a critical global health problem.[1] In the first year of life, adequate iron stores are critical for erythropoiesis and neurocognitive development. Up until about 6 months of age, iron stores acquired prenatally along with a small amount of iron from breast milk are adequate to meet these needs for most healthy full-term infants and as such additional iron is not needed until ≥4 months of age, with the World Health Organization recommendation being 6 months of age.[2-4] After about 6 months of age, supplemental iron is needed by full-term infants and usual dietary recommendations suggest the primary use of iron-containing solid foods.[5]

These recommendations do not fully account for the differences in the relative bioavailability of iron from nonheme iron, including infant formula and from heme iron or from human milk and how these may affect iron status.[6] Determination of total iron absorption has usually combined groups of infants and not separately considered breastfed, mixed fed, and formula-fed infants.[6] Nonetheless, recommendations, including those of the Dietary Guidelines Advisory Committee, 2020, indicate that formula-fed infants are not at substantial risk for low iron intake and do not consider the considerable population of older, mixed fed infants.[7]

We sought to use a well-characterized recent database that provides detailed information on iron intake and sources to calculate the daily absorbed iron intake from infants receiving a variety of milk and formula intakes consistent with usual diets in the US. From this information, we determined the proportion of infants whose diet was below the intake needed to meet calculated absorbed

| | |
|---|---|
| DRI | Dietary reference intakes |
| EAR | Estimated average requirement |
| FITS | Feeding Infants and Toddlers Study |
| WIC | The Special Supplemental Nutrition Program for Women, Infants, and Children |

From the [1]Dell Medical School at the University of Texas at Austin, Austin, TX; [2]RTI International, Durham, NC; and [3]Nestlé Nutrition, Arlington, VA

The Feeding Infants and Toddlers Study 2016 was funded by Nestlé Research, Vers-chez-les-Blanc, Lausanne, Switzerland and analyses described in this publication was funded by Gerber Products Co, Nestlé Nutrition, Arlington, VA 22209. Nestlé Research, in collaboration with research partners RTI International and subcontractor University of Minnesota, designed and implemented the Feeding and Infants and Toddlers Study. Data interpretation and preparation of the manuscript was conducted by S.A. who did so without any form of financial support for this project or his research. S.A. and J.H. declare no conflicts of interest. S.A. does not consult with or receive research financial support from Nestlé. K.F. is employed by Nestlé Nutrition.


https://doi.org/10.1016/j.jpeds.2020.10.071

iron requirements and to further determine the proportion of iron in each group that came from heme iron vs nonheme iron or breast milk.

The aims of this study were to report the iron intake distribution among breastfed (only received breast milk), mixed fed (received breast milk and infant formula), and formula-fed (received only infant formula) 6- to 12- month-old infants; report the percent of infants with iron intakes below the estimated average requirement (EAR) by milk or formula feeding type; calculate an estimate of the amount of absorbed iron consumed by applying established absorption factors for heme, nonheme, and breast milk sources of iron; estimate the percent of infants with calculated absorbed iron intakes below the daily absorbed iron requirement of 0.69 mg (the physiologic requirement) used to set the dietary reference intakes (DRI) for this age group; and determine the contribution of heme, nonheme, and breast milk iron to total calculated absorbed iron intake.[6] These calculations are based on assumptions used in development of these guidelines including using average size and growth rates for infants as well as estimates of absorption which would be affected by individual factors including iron status.

We hypothesized that current dietary practices in the US would lead to relatively low bioavailable iron intake in breastfed and mixed fed infants leading to a risk of inadequate absorbed iron.

## Methods

Conducted in 2002, 2008, and 2016, Feeding Infants and Toddlers Study (FITS) is a nation-wide survey examining food intake and feeding behaviors among infants and children <4 years of age in the US.[8,9] Data reported here are those only from the 2016 FITS study. Trained telephone interviewers obtained informed consent and detailed dietary intake data using the multiple-pass 24-hour recall methodology from eligible caregivers (n = 3235). A subset of caregivers were randomly selected to complete a second 24-hour recall to estimate usual nutrient intake distributions (n = 799). Sample weighting methods were applied to control for bias between the survey sample and the US population. Nutrient intakes were calculated with systems developed by the Nutrition Coordinating Center at the University of Minnesota. The estimated breast milk volume and nutrient composition used in FITS is consistent with the methodology used in the National Health and Nutrition Examination Surveys and by the Institute of Medicine to develop the DRI for infants.[10,11] For breastfed infants, an intake of 600 mL/day was assumed and pumped milk or infant formula was subtracted.[10,12-14] Institutional review boards at the University of Minnesota, RTI International, and Fort Hays University approved the study methods and procedures. A detailed description of the FITS 2016 study design and methodology is available elsewhere.[15]

The EAR is the amount of a nutrient whose intake is determined to meet the needs of 50% of the population.[16] For infants >6 months of age, the EAR for iron of 6.9 mg/day was established using factorial modeling, which considered the amount of iron required for increases in tissue iron, storage iron, and hemoglobin mass and accounting for basal iron losses.[6] An absorbed iron requirement of 0.69 mg/day was determined to be adequate for 50% of the population.[6] Because the bioavailability of iron from foods differ, absorption factors of 50% for breast milk, 20% for heme iron sources, and 5% for nonheme iron sources were applied along with the likelihood infants of that age would consume heme and nonheme iron according to data from the National Health and Nutrition Examination Survey.[6] An overall estimate of 10% absorption was then applied converting the absorbed iron requirement of 0.69 mg/day to a total daily iron intake requirement of 6.9 mg/day (the EAR).[6]

For this analysis, only infants age 6 to 12 months (had not reached their first birthday) who were breastfed (received only breast milk; n = 296), mixed fed (received breast milk and infant formula; n = 102), or formula fed (received only infant formula; n = 448) according to the 24-hour recall were included (n = 846). Infants who received neither infant formula nor breast milk (ie, no milk or cow milk) on the day of the recall were excluded (n = 56). First, iron intake distributions and the percent of infants with iron intakes below the EAR were calculated for the overall population and by milk type (breastfed, mixed fed, and formula fed). Second, 2 registered dietitians familiar with the FITS methodology independently reviewed the extensive list of individual foods captured in the survey and determined if it was a heme or nonheme source of iron. If the food title or description included the words meat (including poultry), meat gravy, or meat broth, it was coded as a heme iron source. Breast milk was coded as breast milk, and all other foods were coded as nonheme iron sources. Together, the dietitians determined the code in the few cases where there was disagreement in the independent assessments.

Once the food map was coded, absorption factors were applied to the total iron content of the food consistent with the DRI methodology as follows: 50% for breast milk, 20% for heme iron sources, and 5% for nonheme iron sources.[6] We then calculated the total amount of iron absorbed daily as the product of the intake and the absorption. We refer to this as the calculated absorbed iron intake. Subsequently, distributions and percent of infants with daily intakes below the calculated absorbed iron requirement of 0.69 mg were determined for the overall population and by milk type.[6] Results for 3-month increments in age (6-9 months and 9-12 months) were also calculated to capture the rapid changes in complementary feeding practices for this age group. Sources of calculated absorbed iron were ranked according to contribution they made to the calculated absorbed iron intake for the overall population by milk feeding type.

Descriptive statistics were calculated for participant characteristics including race, household income, participation in the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), and caregiver education level. Differences between milk feeding types in characteristics, mean iron intakes, mean calculated absorbed iron intakes, percent below the EAR, and percent below the absorbed iron requirement were calculated with unpaired *t* tests. A *P* value of < .05 was considered statistically significant. All statistics were analyzed using the following software: SAS (version 9, SAS Institute Inc) and SAS-callable SUDAAN (version 11, RTI International).

## Results

There were some differences in characteristics among infants with different milk feeding types (**Table I**). Significantly more breastfed infants were non-Hispanic white compared with mixed fed and formula-fed infants. Formula-fed infants were significantly more likely to come from lower income households, participate in WIC, and have caregivers with less education compared with breastfed and mixed fed infants. Significantly, more breastfed infants consumed nonbaby food meat on the day of the 24-hour recall compared with mixed fed and exclusively formula-fed infants, but differences in baby food meat consumption were not significant. Significantly more breastfed and mixed fed infants consumed a dietary supplement compared with formula-fed infants, but iron supplement use was low and differences in use between groups was not significant.

Among exclusively breastfed infants in each age subcategory, the mean total iron intake was significantly lower and the percentage of infants with iron intakes below the EAR was significantly higher compared with mixed fed and formula-fed infants (**Table II**). Mixed fed infants had significantly lower mean iron intakes and the percentage of mixed fed infants below the EAR was significantly higher compared with formula-fed infants. Very few exclusively formula-fed infants had iron intakes below the EAR in either age group.

When absorption factors were applied, mean calculated absorbed iron intakes and the percentage of infants with intakes below the absorbed iron requirement (0.69 mg/day) were significantly different between all milk feeding types in each age group (**Table III**). The percentage of infants below the 0.69 mg/day absorbed iron threshold was higher than the percentage of infants with total daily iron intakes below the EAR (from **Table II**) in every category.

Among breastfed infants, 42% of calculated absorbed iron came from human milk, 47% from nonheme iron sources, and 11% from heme iron sources (**Figure**). Among mixed fed infants, 17% of calculated absorbed iron came from human milk, 79% from nonheme sources, and 4% from heme sources. Among formula-fed infants, 93% of the calculated absorbed iron was from nonheme sources and 7% from heme sources. Although bioavailability of iron from breast milk is high, the overall intake is low.

When the sources of calculated absorbed iron were ranked, the grain group and milk group (human milk and infant

**Table I. Characteristics by milk feeding type for infants 6 to 12 months of age**

| Characteristics | Breastfed (n = 296) | Mixed fed (n = 102) | Formula fed (n = 448) |
|---|---|---|---|
| Child's sex male | 55.4 (2.9) | 57.8 (4.9) | 52.2 (2.4) |
| Child first born | 33.3 (2.9) | 42.6 (5.1) | 39.5 (2.6) |
| Race | | | |
| Hispanic | 11.9 (1.9) | 13.0 (3.4) | 15.5 (1.7) |
| Non-Hispanic white | 77.9 (2.4)*† | 64.0 (4.8)* | 63.9 (2.3)† |
| Non-Hispanic black | 5.8 (1.4)† | 12.0 (3.3) | 17.3 (1.8)† |
| Non-Hispanic other | 5.1 (1.3) | 11.0 (3.1)‡ | 3.4 (0.9)‡ |
| Income (US$) | | | |
| <10 000 | 3.38 (1.05)† | 4.9 (2.13)‡ | 10.49 (1.45)†‡ |
| 10 000-19 999 | 7.43 (1.52) | 4.9 (2.14)‡ | 10.94 (1.47) ‡ |
| 20 000-34 999 | 13.18 (1.97)† | 15.69 (3.6)‡ | 26.56 (2.09)†‡ |
| 35 000-49 999 | 19.93 (2.32) | 23.53 (4.2) | 16.96 (1.77) |
| 50 000-74 999 | 23.31 (2.46)† | 18.63 (3.85) | 16.96 (1.77)† |
| 75 000-99 999 | 18.24 (2.25)† | 19.61 (3.93)‡ | 8.93 (1.35)†‡ |
| 100 000-149 999 | 11.15 (1.83) | 7.84 (2.66) | 6.92 (1.2) |
| ≥150 000 | 3.38 (1.05) | 4.9 (2.14) | 2.23 (0.07) |
| Maternal education | | | |
| High school or less | 14.2 (2.0)† | 16.8 (3.7)‡ | 27.5 (2.1)†‡ |
| Some post-secondary | 22.7 (2.4) | 19.8 (4.0) | 25.9 (2.1) |
| College or graduate | 63.1 (2.8)† | 63.4 (4.8)‡ | 46.7 (2.4)†‡ |
| WIC participant | 25.7 (2.5)† | 33.3 (4.7)‡ | 55.6 (2.3)†‡ |
| Meat intake | | | |
| Nonbaby food | 31.4 (2.7)*† | 18.6 (3.9)* | 21.4 (1.9)† |
| Baby food | 5.4 (1.3) | 2.9 (1.7) | 3.1 (0.8) |
| Supplement with iron | 4.1 (1.2) | 2.9 (1.7) | 2.9 (0.8) |
| Mean volume intake (mL) | | | |
| Formula | n/a | 443 (32) | 918 (17) |
| Human milk | 658 (74) | 379 (21) | n/a |

Milk feeding type defined by 24-hour recalls: Breastfed = received breast milk and no infant formula; mixed fed = received breast milk and infant formula; formula fed = received infant formula and no breast milk.
Values are percent (standard error).
*Breastfed vs mixed fed, *P* < .05.
†Breastfed vs formula fed, *P* < .05.
‡Mixed fed vs formula fed, *P* < .05.

**Table II. Total iron intakes (mg/d) and relationship with feeding type (without absorption factors applied)**

| Feeding types | No. | 10th | 25th | Median | Mean | SE | 75th | 90th | %<EAR |
|---|---|---|---|---|---|---|---|---|---|
| 6-9 Months | | | | | | | | | |
| Overall | 469 | 4.8 | 7.1 | 10.2 | 11.0 | 0.3 | 14.2 | 18.3 | 23.8 |
| Breastfed | 153 | 0.9 | 1.3 | 2.1 | 2.7*† | 0.2 | 3.4 | 5.2 | 95.5*† |
| Mixed fed | 71 | 5.2 | 7.0 | 9.7 | 10.5*‡ | 0.6 | 13.1 | 16.9 | 24.2*‡ |
| Formula fed | 234 | 10.5 | 13.1 | 16.6 | 17.6†‡ | 0.4 | 21.0 | 26.0 | 0.7†‡ |
| 9-12 Months | | | | | | | | | |
| Overall | 434 | 6.0 | 8.7 | 12.3 | 13.2 | 0.3 | 16.8 | 21.5 | 14.0 |
| Breastfed | 143 | 2.2 | 3.3 | 5.2 | 6.5†§ | 0.4 | 8.3 | 12.4 | 66.0*† |
| Mixed fed | 31 | 5.0 | 6.8 | 9.5 | 10.2‡§ | 0.8 | 12.8 | 16.4 | 25.5*‡ |
| Formula fed | 214 | 11.0 | 13.5 | 17.1 | 18.3†‡ | 0.5 | 21.7 | 26.9 | 0.5†‡ |
| 6-12 Months | | | | | | | | | |
| Overall | 902 | 5.3 | 7.8 | 11.3 | 12.1 | 0.2 | 15.5 | 20.0 | 18.9 |
| Breastfed | 296 | 1.1 | 1.8 | 3.3 | 4.5*† | 0.2 | 5.7 | 9.3 | 81.5*† |
| Mixed fed | 102 | 5.1 | 6.9 | 9.6 | 10.4*‡ | 0.5 | 13.0 | 16.7 | 24.6*‡ |
| Formula fed | 448 | 10.7 | 13.3 | 16.8 | 17.9†‡ | 0.3 | 21.4 | 26.5 | 0.6†‡ |

EAR of 6.9 mg/d.
*Statistical comparison of means between feeding types and %<EAR between feeding types within each age group: Breastfed vs mixed fed, *P* < .0001.
†Statistical comparison of means between feeding types and %<EAR between feeding types within each age group: Breastfed vs formula fed, *P* < .0001.
‡Statistical comparison of means between feeding types and %<EAR between feeding types within each age group: Mixed fed vs formula fed, *P* < .0001.
§Statistical comparison of means between feeding types and %<EAR between feeding types within each age group: Breastfed vs mixed fed 9-12 months, *P* = .0002.

**Table III. Total calculated absorbed iron (mg/d) and relationship with feeding type (with absorption factors applied)**

| Feeding types | No. | 10th | 25th | Median | Mean | SE | 75th | 90th | % <0.69* |
|---|---|---|---|---|---|---|---|---|---|
| 6-9 months | | | | | | | | | |
| Overall | 469 | 0.3 | 0.4 | 0.6 | 0.6 | 0.01 | 0.8 | 1.0 | 64.3 |
| Breastfed | 153 | 0.2 | 0.2 | 0.3 | 0.3†‡ | 0.01 | 0.3 | 0.4 | 99.8†‡ |
| Mixed fed | 71 | 0.3 | 0.4 | 0.5 | 0.6†§ | 0.03 | 0.7 | 0.9 | 71.7†§ |
| Formula fed | 234 | 0.6 | 0.7 | 0.9 | 0.9‡§ | 0.02 | 1.1 | 1.3 | 23.4‡§ |
| 9-12 months | | | | | | | | | |
| Overall | 434 | 0.4 | 0.6 | 0.7 | 0.8 | 0.02 | 1.0 | 1.2 | 44.3 |
| Breastfed | 143 | 0.3 | 0.3 | 0.4 | 0.5‡¶ | 0.01 | 0.5 | 0.7 | 91.3†‡ |
| Mixed fed | 31 | 0.3 | 0.4 | 0.5 | 0.6§¶ | 0.04 | 0.7 | 0.9 | 73.2†§ |
| Formula fed | 214 | 0.6 | 0.8 | 0.9 | 1.0‡§ | 0.02 | 1.2 | 1.4 | 15.7‡§ |
| 6-12 months | | | | | | | | | |
| Overall | 902 | 0.4 | 0.5 | 0.7 | 0.7 | 0.01 | 0.9 | 1.1 | 54.3 |
| Breastfed | 296 | 0.2 | 0.2 | 0.3 | 0.4†‡ | 0.01 | 0.4 | 0.6 | 95.8†‡ |
| Mixed fed | 102 | 0.3 | 0.4 | 0.5 | 0.6†§ | 0.02 | 0.7 | 0.9 | 72.2†§ |
| Formula fed | 448 | 0.6 | 0.7 | 0.9 | 1.0‡§ | 0.01 | 1.1 | 1.4 | 19.5‡§ |

*0.69 mg/d is the absorbed daily iron requirement used to establish the EAR.
†Statistical comparison between feeding types within each age group: Breastfed vs mixed fed, $P < .0001$.
‡Statistical comparison between feeding types within each age group: Breastfed vs formula fed, $P < .0001$.
§Statistical comparison between feeding types within each age group: Mixed fed vs formula fed, $P < .0001$.
¶Statistical comparison between feeding types within each age group: Breastfed vs mixed fed 9.0-11.9 months, $P = .0086$.

formula) were the main contributors to total iron intake (**Table IV**; available at www.jpeds.com) for all infants and for bottom and top quartiles of calculated absorbed iron intakes (**Table V** and **Table VI**; available at www.jpeds.com). Infant cereal was the top source of iron among breastfed infants, followed by human milk and meat. Among mixed fed and formula-fed infants, infant formula was the top source of calculated absorbed iron followed by infant cereal. Among meat sources, chicken and turkey were the top contributors to iron, although these contribute relatively little heme iron. Although beef is high in heme iron, it did not contribute ≥0.01 mg/day calculated absorbed iron to the diets of infants in any feeding type categories and, thus, is not listed as a source of iron.

Among infants in the bottom quartile of calculated absorbed iron intakes, human milk or infant formula is the top source contributing to the majority of iron intakes (0.10-0.42 mg/day) (**Table V**). Infant cereal is the second ranked source, but contributes only 0.02-0.04 mg/day of iron. Among infants in the top quartile of calculated absorbed iron, infant cereal is the top source of iron contributing 0.45-0.62 mg/day of absorbed iron and milk is ranked second contributing 0.10-0.65 mg of absorbed iron daily (**Table VI**). Very few infants received infant formula or human milk exclusively and did not receive any complementary foods. Among those in the bottom quartile of calculated absorbed iron intake, 4.0% of breastfed infants, 1.5% of mixed fed infants, and 1.6% of formula-fed infants received no complementary foods. All infants in the top quartile of calculated absorbed iron intake consumed some complementary foods in addition to human milk or infant formula.

## Discussion

We found that the calculated absorbed iron based on current feeding patterns were below that needed to meet requirements for growth and erythropoiesis in a large proportion of 6- to 12- month-old infants. This cohort included infants who were receiving all or part of their feedings from breast milk, as well as some infants who did not receive any breast milk. These data further demonstrate that there is minimal iron intake in all groups from highly bioavailable heme iron sources and that low intakes were substantially similar both in 6- to 9-month-old and 9- to 12-month-old infants, indicating no trend toward increased heme iron intake after solid food intake was well-established.

The determination of iron intake and proportion of children meeting their estimated iron requirements have been derived historically using what is referred to as a factorial approach.[6] In this approach, the dietary iron intake is multiplied by the percentage absorbed and then, after accounting for any excretion in urine, stool, or sweat, this amount is compared with the amount of iron that is needed to meet the needs of the child to provide iron for adequate erythropoiesis. This latter amount is determined based on the average body growth, the amount of iron present in red blood cells, estimated blood volume changes during growth, and any iron that may be expected to be outside of red blood cells. The details of this derivation have been described previously and, although there are some uncertainties in the calculations, especially of blood volume, it is likely to reasonably reflect the actual average daily iron need of 6- to 12-month-old infants.[6]

In evaluating whether a population is meeting its intake target for a nutrient, the key value is the EAR. This is the dietary intake needed, on average, to meet the needs of one-half of all children.[10,16] It is, for iron, much lower than the better known recommended dietary allowance, which is intended to meet the needs of nearly all children in a given age range (as separated by sex for older children and adolescents). It is usual to evaluate a populations sufficiency for iron and other nutrients using a "cut point" analysis, in which the proportion of the population below the EAR is used to determine what proportion of the population has a low intake. However, this determination may underestimate insufficient intakes if the assumptions in the EAR value is falsely elevated as it was derived using calculations of absorbed iron, are higher than are actually achieved.[16] Individual dietary guidance is usually based on the recommended dietary allowance, but for population studies the EAR is the appropriate value. For iron, the recommended dietary allowance is 11 mg/day, which is considerably higher that the EAR of 6.9 mg/day.

Because of concerns that dietary practice has led to lower intakes of both iron supplements and iron-containing foods in the US since the original calculations of the EAR were done, we evaluated the frequency of potentially low bioavailable iron intake using a recent, broadly representative population in the US. To do this, we used the same bioavailability

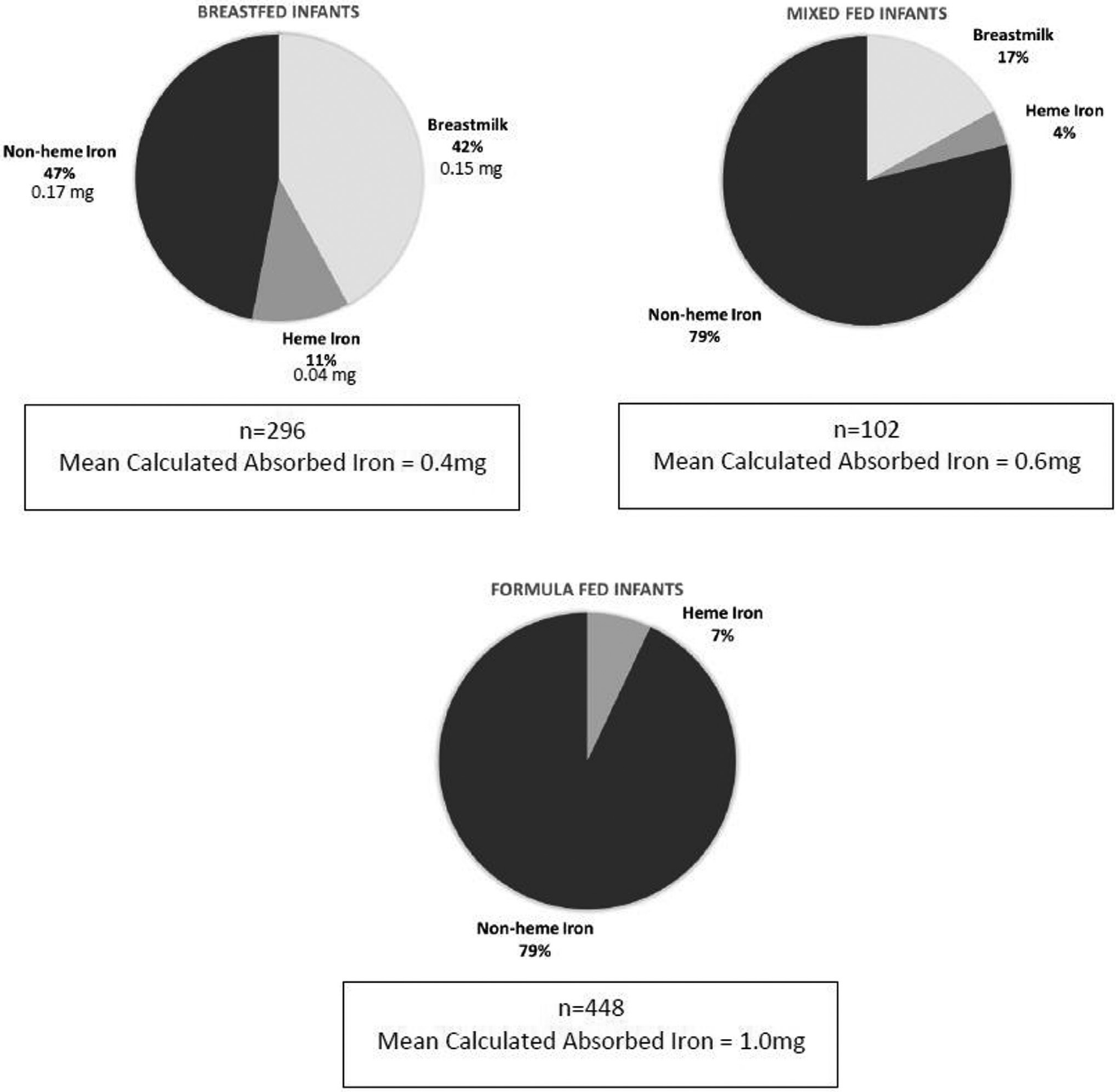


**Figure.** Sources of iron contributing to total calculated absorbed iron by feeding type for infants 6-12 months of age.

estimates as were used in the original derivation, applying them to breast milk, nonheme iron (including infant formula), and heme iron. We then evaluated the total amount of each of these in the diets of the infants and determine the calculated daily absorbed iron.

In considering these data, and recognizing the importance of breast milk, it is important to consider methods to assess and respond to low overall iron intakes, especially extremely low values. Consideration only of the proportion below the EAR or the absorbed iron requirement misses concerns about the proportion with very low absorbed iron. For example, the 10th percentile of daily absorbed iron was only 0.2 mg in breastfed and 0.3 mg in mixed fed infants 6-12 months of age. Even recognizing individual variation in absorption capacity and the possibility that lower iron status would increase the proportion of absorbed iron, these values are far below that needed for adequate erythropoiesis during rapid growth in this age group. Iron deficiency, especially in the first 2 years of life, may be associated with significant lifelong developmental consequences and, as such, although this study did not specifically address markers of iron deficiency, low intakes relative to requirements is of concern related not only to hematologic measures, but also to developmental outcomes.[17]

The likely primary etiology of these low intakes relative to absorbed requirements is a secular decrease in the intake of iron from solid foods. Evaluation of the current compared with the 2008 FITS studies showed a decrease in mean iron intake among 6- to 12- month-old infants from 15.1 to 13.6 mg/day between 2008 and 2016.[18] During the same time, the percentage of infants 6-12 months of age receiving infant cereal decreased from 65% to 52%.[19] Overall, it has been noted that, whereas in 2002 only 7% of 6- to 12- month-old FITS participants had an intake below the EAR overall, by 2016 that value was 18%.[19-21] Of note is that, despite the American Academy of Pediatrics recommendation to provide supplemental iron to breastfed infants beginning at 4 months of age and until solid food iron intake is well-established, few infants in this study as well as others receive supplemental iron (<5% in this study), which may exacerbate the impact of low iron intakes.[22,23]

The database of infants used in this analysis has been well-described as representative of the US population, but social and other changes, including increased food insecurity associated with the 2020 novel coronavirus disease-2019 pandemic, may have changed feeding patterns since the study data were collected.[24] These changes, including decreases in WIC participation (a provider of iron food sources) and concerns about use of cereals such as those related to arsenic in rice-based infant cereals, are likely to have led to current lower, not higher, population intakes of iron since the FITS data were collected in 2016.[25,26]

The calculations of absorbed iron are based on bioavailability estimates used by the Institute of Medicine to establish the DRI.[6] These values may not apply uniformly to all food sources, especially for infant formulas where certain types of formula; for example, soy formulas may have lower bioavailability than others.[27] Intake of breast milk is difficult to estimate precisely, but the value used is consistent with expected values in this age group and small variations would have minimal effect on results owing to the low concentration of iron in breast milk.

Iron bioavailability is affected by a broad range of dietary components, as well as the iron status of the infants.[28] We have chosen not to attempt such a detailed analysis of formula types or different iron sources within the nonheme iron category, because the data do not permit this analysis to be done reliably. Small variability in bioavailability factors for solid foods would not likely have a large effect on diets in infants of this age, for whom small amounts of solid foods are given. New practices, including delayed cord clamping, may affect the iron requirements in this age group and require further investigation. Additionally, results represent those based on average size and growth rates of infants and cannot be used to predict individual infant requirements. Finally, FITS use reported dietary intake from caregivers, which has inherent limitations.[29]

Although it may be thought that low iron intakes and absorbed iron most likely only affects lower income families, this is not necessarily the case in the US. Higher rates of breastfeeding in upper socioeconomic status families, as well as the effectiveness of the WIC program in providing infant formula and iron-containing solid foods might lead to lower iron intakes among higher income compared with lower income families. Among 6- to 12-month-old infants, WIC participants had a significantly lower percentage below the EAR for iron (12.6%) than both lower income (25.6%) and higher income (34%) non-WIC participants.[30] Regardless of the etiology, these data demonstrate that all children need to have consideration of iron intake regardless of socioeconomic status. Those choosing not to provide iron in solid foods should have emphasis given on consideration of supplements.

Pediatricians counseling families should be aware that the possibility of low iron intake exists for all families, regardless of whether the infant is formula fed or breastfed, although this possibility is much higher in infants fed breast milk. This finding may have consequences for long-term outcomes of the infant. Although it is accurate that the absorption of iron from breast milk, especially in older infants, is high, it should be understood that even with a 50% absorption efficiency, the daily intake of iron from breast milk (about 0.2 mg/day) can only meet about 15%-20% of the overall need for iron of the older breastfed infant.[31-33] Further research is needed to define the frequency of iron deficiency in this age group, especially in mixed-fed or exclusively breast-fed infants.

These data support the current recommendations for routine monitoring of all older infants for evidence of anemia using a hemoglobin measurement. Consideration should be given to additional monitoring, not part of current recommendations, for early evidence of iron deficiency without anemia, such as using a serum ferritin, especially in infants who are partially or fully breastfed.[3] Education, both on an individual and a general population level, about the importance of solid food intake such as cereals containing iron and the provision of heme iron for families that include meat in their diet are critical, as are considerations of using supplemental iron when dietary iron intake is low.[34] Introduction of meat can safely be done in 6- to 12- month-old infants and has been demonstrated to be effective on a global basis.[35]

The recent Dietary Guidelines for Americans Advisory Committee concluded in considering diets in the first 24 months that “Every bite counts.”[7] Our data are consistent with this finding related to the value of iron containing solid foods and the need to understand the significant risk of a low iron intake in the diets of 6- to 12- month-old infants. ■

*We thank Susan Pac of Nestlé Nutrition for her contribution and assistance with data coding and Brian Kineman of Nestlé Nutrition for methodological assistance.*

Submitted for publication Sep 4, 2020; last revision received Oct 20, 2020; accepted Oct 28, 2020.

Reprint requests: Steven A. Abrams, MD, Dell Pediatric Research Institute, 1400 Barbara Jorden Blvd., Austin TX 78723. E-mail: sabrams@austin.utexas.edu

## References


1. Kassebaum NJ, Jasrasaria R, Naghavi M, Wulf SK, Johns N, Lozano R, et al. A systematic analysis of global anemia burden from 1990 to 2010. Blood 2014;123:615-24.
2. World Health Organization. Daily iron supplementation in infants and children guideline. 2016. www.who.int/nutrition/publications/micronutrients/guidelines/daily_iron_supp_childrens/en/. Accessed November 18, 2020.
3. Baker RD, Greer FR, Committee on Nutrition American Academy of P. Diagnosis and prevention of iron deficiency and iron-deficiency anemia in infants and young children (0-3 years of age). Pediatrics 2010;126:1040-50.
4. Ziegler EE, Nelson SE, Jeter JM. Iron stores of breastfed infants during the first year of life. Nutrients 2014;6:2023-34.
5. Dewey K, Harrison M. Feeding infants and children from birth to 24 months: summarizing existing guidance. The National Academies Collection. Washington (DC): National Institutes of Health; 2020.
6. Institute of Medicine. Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Washington (DC): National Academies Press; 2001.
7. Dietary Guidelines Advisory Committee. Scientific report of the 2020 Dietary Guidelines Advisory Committee: advisory report to the Secretary of Agriculture and the Secretary of the Health and Human Services. Washinton (DC): Department of Agriculture. Washington; 2020.
8. Briefel RR, Kalb LM, Condon E, Deming DM, Clusen NA, Fox MK, et al. The Feeding Infants and Toddlers Study 2008: study design and methods. J Am Diet Assoc 2010;110:S16-26.
9. Devaney B, Kalb L, Briefel R, Zavitsky-Novak T, Clusen N, Ziegler P. Feeding Infants and Toddlers Study: overview of the study design. J Am Diet Assoc 2004;104:s8-13.
10. Institute of Medicine. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington (DC): The National Academies Press; 2005.
11. Ahluwalia N, Herrick KA, Rossen LM, Rhodes D, Kit B, Moshfegh A, et al. Usual nutrient intakes of US infants and toddlers generally meet or exceed Dietary Reference Intakes: findings from NHANES 2009-2012. Am J Clin Nutr 2016;104:1167-74.
12. Dewey KG, Finley DA, Lonnerdal B. Breast milk volume and composition during late lactation (7-20 months). J Pediatr Gastroenterol Nutr 1984;3:713-20.
13. Dewey KG, Lonnerdal B. Milk and nutrient intake of breast-fed infants from 1 to 6 months: relation to growth and fatness. J Pediatr Gastroenterol Nutr 1983;2:497-506.
14. Kent JC, Mitoulas L, Cox DB, Owens RA, Hartmann PE. Breast volume and milk production during extended lactation in women. Exp Physiol 1999;84:435-47.
15. Anater AS, Catellier DJ, Levine BA, Krotki KP, Jacquier EF, Eldridge AL, et al. The Feeding Infants and Toddlers Study (FITS) 2016: study design and methods. J Nutr 2018;148:1516S-24S.
16. Institute of Medicine. DRI dietary reference intakes: applications in dietary assessment. Washington (DC): National Academies Press; 2000.
17. Lozoff B, Georgieff MK. Iron deficiency and brain development. Semin Pediatr Neurol 2006;13:158-65.
18. Eldridge AL, Catellier DJ, Hampton JC, Dwyer JT, Bailey RL. Trends in mean nutrient intakes of US infants, toddlers, and young children from 3 Feeding Infants and Toddlers Studies (FITS). J Nutr 2019;149:1230-7.
19. Duffy EW, Kay MC, Jacquier E, Catellier D, Hampton J, Anater AS, et al. Trends in food consumption patterns of US infants and toddlers from Feeding Infants and Toddlers Studies (FITS) in 2002, 2008, 2016. Nutrients 2019;11.
20. Fox MK, Pac S, Devaney B, Jankowski L. Feeding Infants and Toddlers Study: what foods are infants and toddlers eating? J Am Diet Assoc 2004;104:s22-30.
21. Bailey RL, Catellier DJ, Jun S, Dwyer JT, Jacquier EF, Anater AS, et al. Total usual nutrient intakes of US children (under 48 months): findings from the Feeding Infants and Toddlers Study (FITS) 2016. J Nutr 2018;148:1557S-66S.
22. American Academy of Pediatrics Committee on Nutrition. In: Kleinman REGF, ed. Pediatric nutrition. 8th ed. Itasca (IL): American Academy of Pediatrics; 2019.
23. Gahche JJ, Herrick KA, Potischman N, Bailey RL, Ahluwalia N, Dwyer JT. Dietary supplement use among infants and toddlers aged <24 months in the United States, NHANES 2007-2014. J Nutr 2019;149:314-22.
24. Abrams SA, Avalos A, Gray M, Hawthorne M. High level of food insecurity among families with children seeking routine care at federally qualified health centers during the coronavirus disease 2019 pandemic. J Pediatr X 2020;4:100044.
25. American Academy of Pediatrics. AAP welcomes FDA announcement on limiting arsenic in infant rice cereal 2016. www.fda.gov/regulatory-information/search-fda-guidance-documents/draft-guidance-industry-action-level-inorganic-arsenic-rice-cereals-infants. Accessed November 18, 2020.
26. National WIC Association. Winter 2019 WIC research to practice 2019. www.nwica.org/winter-2019-wic-research-to-practice. Accessed November 18, 2020.
27. Hurrell RF, Davidsson L, Reddy M, Kastenmayer P, Cook JD. A comparison of iron absorption in adults and infants consuming identical infant formulas. Br J Nutr 1998;79:31-6.
28. Lonnerdal B. Development of iron homeostasis in infants and young children. Am J Clin Nutr 2017;106:1575S-80S.
29. Wu X, Jackson RT, Khan SA, Ahuja J, Pehrsson PR. Human milk nutrient composition in the United States: current knowledge, challenges, and research needs. Curr Dev Nutr 2018;2:nzy025.
30. Guthrie JF, Catellier DJ, Jacquier EF, Eldridge AL, Johnson WL, Lutes AC, et al. WIC and non-WIC Infants and Children Differ in Usage of Some WIC-Provided Foods. J Nutr 2018;148:1547S-56S.
31. Domellof M, Cohen RJ, Dewey KG, Hernell O, Rivera LL, Lonnerdal B. Iron supplementation of breast-fed Honduran and Swedish infants from 4 to 9 months of age. J Pediatr 2001;138:679-87.
32. Domellof M, Lonnerdal B, Abrams SA, Hernell O. Iron absorption in breast-fed infants: effects of age, iron status, iron supplements, and complementary foods. Am J Clin Nutr 2002;76:198-204.
33. Abrams SA, Wen J, Stuff JE. Absorption of calcium, zinc, and iron from breast milk by five- to seven-month-old infants. Pediatr Res 1997;41:384-90.
34. Krebs NF. Food based complementary feeding strategies for breastfed infants: what's the evidence that it matters? Nutr Today 2014;49:271-7.
35. Krebs NF, Mazariegos M, Chomba E, Sami N, Pasha O, Tshefu A, et al. Randomized controlled trial of meat compared with multimicronutrient-fortified cereal in infants and toddlers with high stunting rates in diverse settings. Am J Clin Nutr 2012;96:840-7.

**Table IV. Ranked food sources of calculated absorbed iron by feeding type for infants 6 -12 months of age in the total population***

| Ranks | Breastfed (n = 296) | Iron (mg) | Mixed fed (n = 102) | Iron (mg) | Formula fed (n = 448) | Iron (mg) |
|---|---|---|---|---|---|---|
| 1 | Grains | 0.21 | Milk | 0.27 | Milk | 0.52 |
| | Infant cereal | 0.16 | Infant formula | 0.21 | Infant formula | 0.52 |
| | Family cereal | 0.03 | Human milk | 0.06 | | |
| | Baby finger foods | 0.01 | | | | |
| 2 | Milk | 0.10 | Grains | 0.26 | Grains | 0.32 |
| | Human milk | 0.10 | Infant cereal | 0.23 | Infant cereal | 0.26 |
| | | | Family cereal | 0.01 | Family cereal | 0.03 |
| | | | Baby finger foods | 0.01 | Baby finger foods | 0.01 |
| 3 | Meat/Proteins | 0.04 | Vegetables | 0.02 | Mixed dishes | 0.05 |
| | Meat | 0.03 | Baby food vegetable | 0.02 | Chicken and vegetable | 0.01 |
| | Chicken/turkey | 0.01 | | | Pasta dishes | 0.01 |
| | Nonmeat | 0.01 | | | Baby food dinners | 0.01 |
| 4 | Mixed dishes | 0.03 | Meat/protein | 0.02 | Meat/protein | 0.02 |
| | Baby food dinners | 0.01 | Meat | 0.01 | Meat | 0.02 |
| | | | Chicken/turkey | 0.01 | Chicken/turkey | 0.01 |
| | | | Nonmeat | 0.01 | | |
| | | | Egg | 0.01 | | |
| 5 | Vegetables | 0.02 | Fruit | 0.02 | Fruit | 0.02 |
| | Baby food vegetable | 0.01 | Baby food fruit | 0.01 | Baby food fruit | 0.01 |
| | Nonbaby vegetable | 0.01 | | | | |

*May not add up to 100% because only items contributing ≥0.01 mg iron per capita are reported.

**Table V. Ranked food sources of calculated absorbed iron by feeding type for infants 6 -12 months of age in the bottom quartile of absorbed iron intake (≤25th%ile)***

| Ranks | Breastfed (n = 140) | Iron (mg) | Mixed fed (n = 30) | Iron (mg) | Formula fed (n = 151) | Iron (mg) |
|---|---|---|---|---|---|---|
| 1 | Milk | 0.10 | Milk | 0.18 | Milk | 0.42 |
| | Human milk | 0.10 | Infant formula | 0.11 | Infant formula | 0.42 |
| | | | Human milk | 0.07 | | |
| 2 | Grains | 0.02 | Grains | 0.02 | Grains | 0.08 |
| | Infant cereal | 0.01 | Infant cereal | 0.01 | Infant cereal | 0.04 |
| | Baby finger foods | 0.01 | Baby finger foods | 0.01 | Family cereal | 0.02 |
| | | | | | Baby finger foods | 0.01 |
| 3 | Vegetables | 0.01 | Vegetables | 0.02 | Fruit | 0.02 |
| | Baby food vegetable | 0.01 | Baby food vegetable | 0.02 | Baby food | 0.01 |
| 4 | Fruit | 0.01 | Fruit | 0.01 | Mixed dishes | 0.02 |
| | Baby food | 0.01 | | | Baby food dinners | 0.01 |
| 5 | Meat/protein | 0.01 | Mixed dishes | 0.01 | Meat/protein | 0.02 |
| | Meat | 0.01 | Soup | 0.01 | Meat | 0.01 |
| | | | | | Chicken/turkey | 0.01 |

*May not add up to 100% because only items contributing ≥0.01 mg iron per capita are reported.

**Table VI. Ranked food sources of calculated absorbed iron by feeding type for infants 6 -12 months of age in the top quartile of absorbed iron intake (≥75th percentile)**

| Ranks | Breastfed (n = 90) | Iron (mg) | Mixed fed (n = 27) | Iron (mg) | Formula fed (n = 123) | Iron (mg) |
|---|---|---|---|---|---|---|
| 1 | Grains | 0.54 | Grains | 0.64 | Grains | 0.73 |
| | Infant cereal | 0.45 | Infant cereal | 0.62 | Infant cereal | 0.62 |
| | Family cereal | 0.06 | Family cereal | 0.01 | Family cereal | 0.08 |
| | Baby finger foods | 0.02 | Baby finger foods | 0.01 | Baby finger foods | 0.02 |
| | Pasta/rice | 0.01 | | | | |
| 2 | Milk | 0.10 | Milk | 0.35 | Milk | 0.65 |
| | Human milk | 0.10 | Infant formula | 0.29 | Infant formula | 0.64 |
| | | | Human milk | 0.05 | | |
| 3 | Meat/protein | 0.07 | Meat/protein | 0.03 | Mixed dishes | 0.09 |
| | Meat | 0.05 | Meat | 0.01 | Pasta dishes | 0.03 |
| | Chicken/turkey | 0.03 | Fish/shellfish | 0.01 | Baby food dinners | 0.03 |
| | Hotdog/cold cut | 0.01 | | | Chicken and vegetable | 0.02 |
| | Unspecified | 0.01 | | | Beef and vegetable | 0.01 |
| 4 | Mixed dishes | 0.06 | Vegetables | 0.03 | Meat/protein | 0.04 |
| | Baby food dinners | 0.02 | Baby food vegetable | 0.03 | Meat | 0.04 |
| | Beef and vegetable | 0.01 | | | Chicken/turkey | 0.02 |
| | Pork and vegetable | 0.01 | | | Hot dog/cold cut | 0.01 |
| | Pasta dishes | 0.01 | | | Sausage | 0.01 |
| | Soup | 0.01 | | | | |
| 5 | Vegetables | 0.03 | Fruit | 0.02 | Vegetables | 0.03 |
| | Baby food vegetable | 0.01 | | | Baby food vegetable | 0.02 |
| | Nonbaby vegetable | 0.01 | | | | |

*May not add up to 100% because only items contributing ≥0.01 mg iron per capita are reported.