Iron Absorption Is More Closely Related to Iron Status Than to Daily Iron Intake in 12- to 48-Mo-Old Children

Mary Frances Lynch,2-4 Ian J. Griffin,2-4 Keli M. Hawthorne,3 Zhensheng Chen,3 Maria G. Hamzo,3 and Steven A. Abrams2-4*

Abstract

Few studies have evaluated iron absorption in small children after the first year of life. Our objectives were to examine the relations among iron intake, iron absorption, and iron status in a group of healthy children. We studied 28 children, ages 12 to 48 mo, after a 7-d home adaptation to a diet representative of their usual daily mineral intake. A multi-tracer stable isotope study was performed to assess iron absorption both from a meal (58Fe) and from a reference iron dose (57Fe) given with ascorbic acid without a meal. Iron intake was 6.9 ± 2.4 mg, approximately the 35th percentile of typical U.S. intakes. Absorption of 58Fe was related to serum ferritin ($r^2 = 0.319, P = 0.0018$) and more so to reference dose iron absorption ($r^2 = 0.653, P < 0.0001$). Iron absorption was negatively correlated with zinc intake ($r^2 = 0.25, P = 0.0049$) but was not correlated with iron intake ($P = 0.20$). However, zinc intake was not correlated with measures of iron status, including reference dose iron absorption and serum ferritin ($r^2 < 0.1, P > 0.25$). Total absorbed iron was similar to needs estimated by the Institute of Medicine. We conclude that iron absorption in young children is more closely related to iron status than to iron intake. Reference dose iron absorption may be superior to serum ferritin as a surrogate measure for iron status in this age group. Although zinc intake may affect iron absorption from a meal, it does not appear to have a detectable effect on overall iron status in otherwise well-nourished children. J. Nutr. 137: 88–92, 2007.

Introduction

Iron deficiency can lead to anemia, developmental delay, and irreversible cognitive impairment (1). Young children (1-to 4-yr-old) are especially vulnerable to these adverse consequences of iron deficiency, because a large portion of nervous system development occurs during the first few years of life. Despite the importance of iron nutrition, there are few data on iron absorption from children consuming typical diets in the United States. Indeed, the recent Dietary Reference Intakes mostly used data from other age groups to establish an estimated average requirement (EAR) of 3 mg/d for 1- to 4-yr-old young children. This intake is below the 5th percentile of usual intakes in the United States according to the Continuing Survey of Food Intakes in Individuals (data for children between 1 and 4 y of age; mean intake 10.9 mg/d, SEM 0.2 mg/d, 5th centile 5.6 mg/d) (1).

However, diets in children this age are considerably different from those of either infants or older children and the assumptions used to establish the EAR may not be accurate. Therefore, it is important to evaluate the relations among iron intake, absorption, and iron status directly in small children. We hypothesized that percent iron absorption would be negatively correlated with both iron intake and iron status but that iron status would be a more important determinant of percent iron absorption than intake.

Subjects and Methods

Healthy children ages 12–48 mo in the greater Houston area were recruited through public advertising. Subjects were selected to reflect the approximate racial and ethnic distribution of the greater Houston population. The Institutional Review Board of Baylor College of Medicine and Affiliated Hospitals approved the protocol and informed written consent was obtained from the subjects’ parents for all studies.

Screening visit. Children were eligible for enrollment if they were healthy, not taking any medications (except multivitamins), were born at term (≥37 wk gestation) and had a birth weight ≥2500 g. Children were excluded from participating if they had chronic health problems, were below the 3rd or above the 97th percentile of weight-for-age or height-for-age, or were below the 5th or above the 95th percentile of weight-for-height. Those subjects taking multivitamins were required to discontinue them 2 wk prior to participating in the mineral absorption study.

The research dietitian met with the parent and obtained a complete dietary history to evaluate usual daily micronutrient and energy intake.
Dietary intake data were collected using analyzed using Nutrition Data System for Research software versions 5.0 and 2005, developed by the Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN.

**Home dietary adaptation.** After screening, a dietary plan was developed for each child that would be consumed at home for the 7 d prior to the inpatient mineral absorption study and would be similar to the subject’s usual home diet. This was to ensure that children did not alter their eating habits immediately prior to the mineral absorption study. All foods and beverages to be consumed during these 7 d were provided by the research center and were preweighed prior to delivery to the family. Parents were instructed to return all the uneaten food and beverage items for the first 3 d so items could be postweighed.

**Isotope preparation and mineral absorption study.** 57Fe (93% enrichment) and 58Fe (>96% enrichment) were purchased from Trace Sciences. Iron isotopes were converted to the sulfate as previously described (2) and tested for sterility prior to use.

At the end of the home adaptation period, patients were admitted to the General Clinical Research Center at Texas Children’s Hospital, Houston, Texas, for the mineral absorption study. On the morning of the inpatient study, subjects had 3 mL of blood collected for measuring baseline hemoglobin and serum ferritin concentrations, using topical 4% lidocaine cream (L-M-X-4, Ferndale Laboratories) as an anesthetic. Subjects were then given breakfast, which included 30 mL of apple juice to which 0.8 mg of 58Fe as ferrous sulfate was added. Another 30 mL of apple juice that was labeled with an additional 0.8mg of 58Fe was given with lunch. Each meal provided approximately one-third of the daily iron, calcium, and zinc intake of the subject. Menus for the inpatient study visit were based on the subject’s usual mineral intake that they had received at home for the previous 7 d. All foods and beverages during the inpatient visits were pre- and postweighed to accurately determine intake. Dietary intakes used in the results section were based on these intakes.

On the evening of the first inpatient day, 3 mg of 57Fe mixed with 30 mL of white grape juice and 1 mL of Tri-vi-sol, containing 35 mg of ascorbic acid (Mead Johnson Nutritional) was given as a reference dose. This represents iron absorption under optimal conditions (aqueous solutions given with vitamin C in the fasted state). It is an alternative measure of iron status and a method of correcting for between-subject differences in iron absorptive capacity. No food or drinks were given for 2 h before or 2 h after this dose. Subjects were discharged after completion of the mineral stable isotope study and returned for an outpatient visit 14 d after isotope administration for a blood draw to determine the enrichment of the red blood cells with 57Fe and 58Fe.

**Isotope ratio measurement and calculation of mineral absorption.** Iron isotope ratios were measured using high-resolution inductively coupled plasma mass spectrometry (Element 2, ThermoQuest Finnigan) as previously described (3).

Iron absorption was calculated from the red cell incorporation of the isotope at the 14-d blood draw, assuming that 90% of absorbed iron was incorporated into red blood cells (4). An estimated total blood volume of 65 mL/kg was used for this calculation.

**Biochemical methods.** Hemoglobin concentration was measured using standard clinical methods and serum ferritin was measured using a chemiluminescence immunoassay (Elecsys 1010/2010, Roche Diagnostics). Anemia was defined as a hemoglobin concentration below 110 g/L and iron deficiency as a ferritin concentration below 15 μg/L (5).

**Statistical analysis and sample size determination.** Comparisons were made between iron intake and fractional absorption using linear regression analysis. The relations among iron intake, fractional iron absorption, and iron status (assessed using serum ferritin and reference dose iron absorption) were assessed using multiple regression analysis. Single regression, 1-sample t tests, 2-sample t tests, and Fisher’s exact test were used as appropriate. Data were analyzed using SPSS for Windows version 13 and StatsView 5.0.1 for Macintosh (SAS). Power calculations were carried out using DSTPLAN version 4.2 (MD Anderson Cancer Center). Values for iron absorption and serum ferritin were log-transformed (to the natural log, ln) prior to analysis to normalize their distribution.

The total absorbed iron was calculated from the product of the percent iron absorption and iron intake. It was compared to the estimated requirement for absorbed iron for this age range, 0.54-0.64 mg/d (1), using 1-sample t tests with hypothesized means of 0.54 and 0.64. All data are presented as means ± SD unless otherwise noted.

We estimated that a sample of 29 subjects would have allowed for a power of 0.8 (β = 0.2) to detect a correlation of 0.5 between iron intake and fractional iron absorption with a P-value of 0.05 (n = 0.05). A total of 31 subjects were recruited and enrolled in the study to ensure that this number completed the study. Two subjects did not successfully complete the protocol due to failure to comply with study procedures or follow-up. In-patient weighed home dietary records were available for 23 of the 28 subjects.

### Results

**Subject demographics.** Iron absorption was successfully measured in 28 subjects (15 girls and 13 boys), whose age was 30.9 ± 11 mo, body weight was 12.9 ± 2.4 kg, and height was 90 ± 9 cm. Their hemoglobin concentration was 122 ± 11 g/L and their geometric mean serum ferritin concentration was 21.5 μg/L (interquartile range 12–32). The ethnic distribution of the study population was 46% Caucasian, 29% Hispanic, 17% African American, and 7% multi-ethnic. Ethnicity was initially considered as a covariate in each analysis but was not significantly related to any results and was omitted from the final analyses. There were no gender differences for any of these characteristics, so gender was not used as a covariate in the final analysis. Iron intake was 6.9 ± 2.4 mg and zinc intake was 5.2 ± 2.1 mg. Ten of the subjects consumed multivitamins prior to the study, 5 of them with iron. All subjects discontinued their multivitamins at least 2 wk before the start of the study. One subject had a serum ferritin concentration of 117 μg/L that was thought to be due to an upper respiratory infection at the time of the mineral absorption study and this value was excluded from analysis. Four subjects (14%) were mildly anemic (100–109 g/Hb/L), but only 1 subject had iron deficiency anemia (Hb <110 g/L and ferritin <15μg/L). Eight subjects (28%) had iron deficiency without anemia.

Baseline characteristics and inpatient mineral intakes of the iron-deficient subjects and the iron-sufficient subjects were similar (Table 1). Mineral intakes during the home adaptation period were similar and are not shown.

#### TABLE 1 Baseline characteristics of iron-deficient and iron-sufficient 12- to 48-mo-old children

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Iron deficient, n = 9</th>
<th>Iron sufficient, n = 19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender, % male</td>
<td>56</td>
<td>42</td>
</tr>
<tr>
<td>Age, mo</td>
<td>26 ± 9</td>
<td>33 ± 11</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>12.2 ± 1.9</td>
<td>13.2 ± 2.6</td>
</tr>
<tr>
<td>Height, cm</td>
<td>86.5 ± 7.2</td>
<td>91.4 ± 9.5</td>
</tr>
<tr>
<td>Hb, g/L</td>
<td>121 ± 11</td>
<td>122 ± 12</td>
</tr>
<tr>
<td>Serum ferritin, μg/L</td>
<td>9.8 ± 3.4</td>
<td>32.1 ± 14.5*</td>
</tr>
<tr>
<td>Nutrient intakes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron, mg/d</td>
<td>7.3 ± 2.5</td>
<td>6.4 ± 2.3</td>
</tr>
<tr>
<td>Zinc, mg/d</td>
<td>5.4 ± 2.1</td>
<td>5.2 ± 2.0</td>
</tr>
<tr>
<td>Copper, ug/d</td>
<td>41 ± 13</td>
<td>42 ± 13</td>
</tr>
<tr>
<td>Calcium, mg/d</td>
<td>636 ± 198</td>
<td>542 ± 218</td>
</tr>
<tr>
<td>Phytate, mg/d</td>
<td>92 ± 97</td>
<td>166 ± 108</td>
</tr>
<tr>
<td>Vitamin C, mg/d</td>
<td>159 ± 172</td>
<td>189 ± 131</td>
</tr>
</tbody>
</table>

1 Values are means ± SD or %.* Different from iron deficient, P < 0.0001.
2 Serum ferritin, <15 μg/L.
3 During inpatient mineral absorption study.
Relations among iron intake, iron status, and iron absorption. When the effects of iron intake, serum ferritin, and reference dose $^{57}$Fe absorption on iron absorption from a meal $^{58}$Fe were evaluated individually using linear regression analysis, $^{58}$Fe absorption was correlated with both serum ferritin ($y = 4.18 - 0.66x, r^2 = 0.319, P < 0.0001$; Fig. 1A) and $^{57}$Fe absorption ($y = 0.97x - 0.359, r^2 = 0.654, P < 0.0001$; Fig. 1B) but not with iron intake during the in-patient stay ($y = 2.98 - 0.11x, r^2 = 0.084, P = 0.155$) or during the home adaptation period ($y = 2.62 - 0.06x, r^2 = 0.019, P = 0.55$).

When iron intake was included in a multiple regression model with either measure of iron status, similar results were obtained. Iron absorption from a meal $^{58}$Fe was negatively correlated with serum ferritin, $t = -3.5, P = 0.0016$ but not iron intake ($t = -1.1, P = 0.29$) (adjusted $r^2$ of model = 0.334). Similarly, $^{58}$Fe absorption was correlated with reference dose $^{57}$Fe iron absorption ($t = 6.6, P < 0.0001$) but not with iron intake ($t = -1.3, P = 0.19$) (adjusted $r^2$ of model = 0.615). Iron intake during the in-patient admission was not correlated with either serum ferritin concentration ($t = 0.9, P = 0.38, r^2 = 0.03$) or reference dose absorption ($t = -1.0, P = 0.34, r^2 = 0.05$) when these were evaluated individually by linear regression analysis. Similar results were obtained using iron intake during the home adaptation period.

When the amount of heme and nonheme iron that were part of the diet were calculated, heme iron was $34.7 \pm 2.6\%$ of the total iron intake. There was no association between the percent or total heme iron intake and any outcome variable related to iron absorption or status. Hemoglobin concentration was not correlated with iron absorption or iron status ($P > 0.2$). The analysis of the relations, or lack thereof, between iron intake and iron absorption or iron status were not substantially altered when total iron intake was replaced as the independent variable by iron intake from nonmeat sources or by nonheme iron intake (data not shown).

Total iron absorption vs. requirements. Total absorbed iron (product of $^{58}$Fe percent absorption and iron intake) was $0.79 \pm 0.69$ mg/d (geometric mean 0.56 mg/d) with a range of 0.10–3.00 mg/d. The iron intake of our subjects, 6.9 mg/d, was at approximately the 35th percentile of U.S. intakes, well above the current EAR for iron of 3 mg/d. The Institute of Medicine estimated the requirement for absorbed iron in this age range to be $0.54$–$0.64$ mg/d (1). Thirteen subjects (45%) met the lower of these estimates of at least 0.54 mg/d and the total absorbed iron of the study population did not differ from 0.54 mg/d (1-sample $t$ test, $P = 0.068$) or from 0.64 mg/d (1-sample $t$ test, $P = 0.26$).

We compared the percent iron absorption from a meal $^{58}$Fe of the 9 subjects with a serum ferritin $<15 \mu$g/L with that of subjects with a serum ferritin $\geq15 \mu$g/L. The iron intake in the iron-deficient subjects was $6.2 \pm 2.5$ mg/d, similar to the $7.3 \pm 2.5$ mg/d intake in the iron-sufficient subjects (Table 1, $P = 0.37$). Similarly, during the home adaptation period, iron intakes did not differ ($6.8 \pm 2.1$ mg/d vs. $5.5 \pm 1.0$ mg/d; $P = 0.21$). Among the iron-deficient subjects, 56% (5 of 9) absorbed 0.54 mg/d or more as opposed to 37% (7 of 19) in the iron-sufficient group (Fisher’s exact test, $P = 0.43$). Iron absorption of the iron-deficient subjects (geometric mean 13.7% tended to be higher than in iron-sufficient subjects (geometric mean 7.2%) ($P = 0.053$). After controlling for the effect of zinc intake on iron absorption, the iron-deficient subjects had a significantly greater total mean iron absorption of 0.96 $\pm$ 0.6 mg/d (geometric mean 0.82 mg/d) compared with 0.71 $\pm$ 0.75 mg/d (geometric mean 0.49 mg/d) in iron-sufficient subjects ($t = 2.36, P = 0.0296$). We also compared reference dose iron absorption ($^{57}$Fe) in the iron-deficient and iron-sufficient subjects. The iron-deficient subjects absorbed $23.1 \pm 14.7\%$, whereas iron-sufficient subjects absorbed $14.0 \pm 9.9\%$ ($P = 0.023$).

The EAR for iron intake in this age group is 3 mg/d (1). Only 4 subjects consumed $<4$ mg/d and none consumed $<3$ mg/d. Of these 4 subjects, 2 were iron deficient and 2 were iron sufficient. The 2 iron-deficient subjects had percentage iron absorptions of 34 and 28% and consequently absorbed 1.34 and 0.98 mg/d, respectively. In contrast, the iron-sufficient subjects had percentage iron absorptions of 9 and 5% resulting in absorption of 0.28 and 0.16 mg/d, respectively.

Effects of other nutrients on iron absorption. The effect of intake of other minerals during the in-patient stay on percent iron absorption were assessed using multiple regression analysis, correcting for reference dose iron absorption. Iron absorption was not affected by iron intake ($t = 1.6, P = 0.13$) or calcium intake ($t = 0.9, P = 0.39$) but was inversely related to zinc intake ($t = -2.7, P = 0.012$) and positively related to reference dose iron absorption ($t = 7.9, P < 0.0001$) (adjusted $r^2$ of the model = 0.738). When intake during the home adaptation period was substituted for intake during the in-patient stay, the model explained less of the variability in percent iron absorption (adjusted $r^2 = 0.677$) and the effect of zinc intake was no longer significant ($t = -1.1, P = 0.28$).

Iron status, as assessed using serum ferritin, was unaffected by zinc intake ($t = -0.16, P = 0.88$), calcium intake ($t = -0.43$, data not shown).
Iron absorption in young children

P = 0.68), or iron intake (t = 0.44, P = 0.66), but the effect of reference dose iron absorption was significant (t = −2.8, P = 0.0112) (adjusted $r^2 = 0.170$). When weighed dietary intakes during the home adaptation period were used instead of the weighed intake during the in-patient admission, the effect of calcium intake (t = 1.89, P = 0.08) and iron intake (t = 1.69, P = 0.11) remained nonsignificant, but zinc intake (t = −2.2, P = 0.043) and reference dose iron absorption (t = −2.7, P = 0.017) were significant (adjusted $r^2$ of the model = 0.326).

The effects of enhancers and inhibitors of iron absorption were assessed in a similar manner. Percent iron absorption was not related to phytic acid intake (t = −1.8, P = 0.08) or vitamin C intake (t = −0.32, P = 0.75) but was related to reference dose iron absorption (t = 6.6, P < 0.0001). Likewise iron status, as assessed using serum ferritin, was not related to phytic acid intake (t = 1.8, P = 0.08) or vitamin C intake (t = 2.0, P = 0.06) but was related to reference dose iron absorption (t = −3.5, P = 0.0022). Iron intake was included in each of these models but was not significantly related to iron absorption.

Discussion

We found that iron absorption was negatively related to measures of iron status but not significantly related to iron intake. The relation with serum ferritin was similar to that shown previously for children aged 13–26 mo (6) and 5–10 mo (7). Although iron status must in part be explained by differences in iron intake, we could find no direct relation between percent absorption of iron and dietary intake across intakes similar to those typically found in healthy children in the United States. This likely is in part due to the relatively high intakes and overall adequate diets found among this population.

Other studies in infants and small children have shown mixed results regarding the impact of iron intake on fractional absorption (8–10). This may be related to multiple factors, including variable iron loss in the children, differences in iron requirements, and long-term patterns of intake of inhibitors and enhancers of iron absorption. We did not identify effects of vitamin C, phytic acid, or heme-iron intake on iron absorption in this population, but the range of intakes studied was relatively narrow. Furthermore, 10 of the subjects reported consuming multivitamins, which they stopped prior to the study. Their vitamin C intake during the study may, therefore, have underestimated their long-term vitamin C intake. Likewise, 5 of these subjects took iron-containing multivitamins prior to the study, so the iron intake during the study may have underestimated their long-term iron intake. However, excluding these subjects did not change the results of the analysis (results not shown) and no relation between iron intake and iron status measures (serum ferritin or reference dose iron absorption) was observed.

Although serum ferritin is widely used clinically as a marker of iron status, it and other biochemical markers may be altered by intercurrent infections or other inflammatory processes. In small studies of endpoints such as iron absorption, it may be most useful to compare populations using the reference dose iron absorption. This method measures iron absorption under presumably optimal circumstances for absorption (with vitamin C and without any food). In infants, overnight food deprivation is not possible and reference dose iron absorption has been found to be unreliable as a marker of iron status in some studies of infants (11). However, the reference dose method may be more reliable in small children who can fast for several hours so that reference dose absorption is unaffected by the intake of foods shortly before or after the reference dose is given.

In this study, we found that reference dose iron absorption was much more closely related to food iron absorption than was the serum ferritin concentration. Although it is possible that this partly reflects similar patterns of dietary inhibition, that explanation is less likely for 2 reasons. First, there was a much higher absorption of the reference dose than meal iron. Second, there was a lack of a relation between reference dose iron absorption and zinc intake, whereas a strong relation was observed for the meal iron absorption. This suggests that reference dose iron absorption more fully corrects for between-subject differences in food iron absorption than does the serum ferritin concentration.

The requirement for absorbed iron is 0.54–0.64 mg/d in this age group (1). This value accounts for daily iron deposition in hemoglobin, nonstorage and storage iron, and for fecal iron loss. Our subjects had mean intakes similar to the current recommended dietary allowance of 7 mg/d and far above EAR of 3 mg/d. Our subjects absorbed a mean of 0.79 mg/d of iron; although the range of absorbed iron was wide (0.1–3 mg/d), the amount of absorbed iron for the study population as a whole was similar to the requirement estimated by the Institute of Medicine. This is reassuring, as it suggests that intakes near the lower end of the range of intakes (but above the EAR) typically consumed in the US lead to adequate amounts of absorbed iron.

When the subjects were divided into those who had evidence of iron deficiency and those who did not, the iron-deficient subjects had significantly higher total iron absorption and were more likely to meet the requirement for absorbed iron. One possible explanation for this finding is that iron-sufficient subjects, who can mobilize iron from ferritin stores, may have lower daily requirements for absorbed iron. Previous data have shown that 1 μg/L of ferritin is equivalent to ~140 μg of storage iron per kg of body weight (12). Our subjects, with a mean weight of 12.7 kg, would therefore average 1.8 mg of storage iron per 1 μg/L of ferritin (total of 26.7 mg of storage iron for each additional 15 μg/L of ferritin), a considerable reserve. Another explanation may be the large individual variation in daily iron losses. A recent study in which iron absorption and losses were measured in children ages 13–26 mo (6) demonstrated a high degree of inter-subject variability in both absorption and losses, but in individual subjects, absorption and iron losses were positively correlated (i.e. those subjects with greater iron losses absorbed more iron and vice versa). Mean iron losses were 0.24 mg/d but ranged from 0.07 to 0.55 mg/d. The most recent Dietary Reference Intakes expected requirement of at least 0.54 mg/d absorbed iron estimates 0.33 mg/d of iron losses in this age group. Only 0.21 mg/d of iron is needed daily to meet the needs of hemoglobin, storage iron, and nonstorage iron. (1). It is possible that many subjects can meet their individual iron needs with absorption <0.54 mg/d if their daily losses are low. A final explanation would be differences in iron requirements due to differences in body composition, growth, or blood volume, with subjects with lower blood volume, perhaps due to higher adiposity, having lower iron requirements.

We found a significant negative relation between zinc intake and iron absorption from a meal. This was seen for the in-patient day but was not for the adaptation period. The negative impact of zinc on iron absorption when both are administered as aqueous solutions between meals has been described previously (13,14), but previous data suggest that zinc does not interfere with iron absorption even at zinc:iron ratios as high as 5:1 when both minerals are given with a meal (13,15). Zinc intake during the in-patient admission did not affect iron status, suggesting that the inhibition may not be clinically important. However, zinc intake during the adaptation period was inversely related to iron absorption.
status as assessed by the serum ferritin. In may be, therefore, that the zinc intake during the adaptation period more accurately measures longer term zinc intake, which is most likely to modify iron status, whereas the in-patient weighed record more accurately assessed short-term intake that was most likely to affect iron absorption during the stable isotope study. Further data are needed to evaluate this effect, as few data are available in small children.

Iron absorption is inversely related to iron status and not closely related to daily iron intake in 12- to 48-mo-old children with high iron intakes. Reference dose iron absorption more completely corrects for between-subject differences in iron absorption from food than does the serum ferritin concentration.

Iron intakes consistent with the Continuing Survey of Food Intakes in Individuals 35th percentile lead to adequate mean absorbed iron in this age group. The current estimated absorbed iron requirement of 0.54–0.64 mg/d may overestimate the needs of iron-sufficient subjects as evidenced by the apparent down-regulation of iron absorption when iron needs decrease.

Zinc intake in the diet had a negative impact on meal-associated iron absorption in this study and may have a negative effect on iron status.

Acknowledgments
We thank Leslie Cruz and Dana McDonald for their help with patient enrollment and study visits, and Penni Hicks her support and advice.

Literature Cited