Adjustment of Iron Intake for Dietary Enhancers and Inhibitors in Population Studies: Bioavailable Iron in Rural and Urban Residing Russian Women and Children

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ABSTRACT Although determining iron intakes is essential in assessing adequacy of iron in the diet, estimating iron availability may be more useful for evaluating whether iron requirements are met. Our objectives were to describe the dietary information, analytical steps, and computer algorithms needed for iron bioavailability adjustments and to demonstrate the effects of various dietary factors on calculated iron absorption. Our study was based on 9890 women and children participating in the Russian Longitudinal Monitoring Survey. Between August 1992 and February 1993, two 24-h recalls were collected from each participant, and total, heme and nonheme iron intakes were calculated. Nonheme iron availability was adjusted for meat, fish and poultry and vitamin C consumed in the same meal and then further adjusted for tea and phytates. We found mean total iron intakes to be comparable to those of women of reproductive age in the United States and lower than those of United States children. When these intakes were adjusted for enhancers and inhibitors of absorption, the iron bioavailability in these vulnerable Russian groups was extremely low. Mean bioavailable iron as well as the 25th–75th percentile ranges of intake were below the bottom of the range of requirements, indicating that iron adequacy in this population may be considerably less than expected based on total iron intakes alone. Furthermore, rural and urban food availability had a significant effect on iron bioavailability. Future research on dietary iron adequacy should be based on estimates of available iron by collecting meal-level dietary data and using detailed information on mixed dishes and phytates. J. Nutr. 127: 1456–1468, 1997.

KEY WORDS: • absorption • biological availability • humans • iron • rural residency

Iron deficiency continues to be one of the most common nutritional deficiencies in the world. An estimated 30% of the world’s population is anemic, with just under half of these—approximately 600 million cases—due to impaired iron status (Carpenter and Mahoney 1992, Cook et al. 1994). Although anemia is its most clearly recognizable sign, iron deficiency can produce other adverse outcomes even before any noticeable drop in hemoglobin concentrations. Specifically, iron deficiency has been linked with decreased immune function and resistance to infection, diminished work capacity, and increased risk of delivery of preterm and low-birth-weight infants. In infants and children, it has also been associated with diminished cognitive development and learning capacity, with effects that may last into adulthood (Cook et al. 1994, National Research Council 1989).

Given the potential consequences of iron deficiency, determination of iron intakes is a useful strategy for assessing the adequacy of the diet to meet iron requirements. The amount of absorbed iron required to replace average daily basal losses in adult men is approximately 1 mg/d; for women, an additional 0.5 mg/d on average is required to replace menstrual loss (National Research Council 1989). Importantly, however, absorption of iron is highly variable, dependent not only on the iron status of the individual, but also on other factors in the diet that enhance or inhibit its absorption. As such, calculating iron availability is as important as determining total iron intakes when evaluating the adequacy of iron in the diet. Indeed, adjustment for bioavailability may provide a more realistic picture of whether or not iron requirements are met in a population than would a simple assessment of total iron intake.

The purpose of this article is threefold: 1) to describe the specific dietary information needs for conducting these analyses, 2) to present the analytical steps and computer algorithms needed to adjust for iron availability, and 3) to demonstrate the extent to which other dietary factors—specifically, meat, fish and poultry (MFP), vitamin C, tea, and phytates—affect calculated absorption of iron in a population at risk. For this last objective, we present results of adjustment for iron bioavailability.
availability in a sample of Russian women and children and compare results for urban and rural residents.

SUBJECTS AND METHODS

Study population. Data for this study were taken from Rounds 1 and 2 of the Russian Longitudinal Monitoring Survey, a national survey designed to monitor the socioeconomic and health status of the Russian population. Subjects were selected for the survey through a three-stage stratified cluster sampling scheme. Data for Round 1 of the survey were collected between August and October 1992, during which 6485 Russian households throughout Russia were sampled, resulting in a total study population of 16,845 individuals. Round 2 was conducted for the same subjects approximately 6 mo later. The subsample on which this study is based consisted of 9890 Russian women and children for whom repeat dietary information was available. Because few women reported that they were pregnant (n = 44) and estimates are unlikely to change by excluding them, results are reported for all women. Sample weights were used in the analyses to adjust for the sampling design and the response rates at different centers of the study.

Dietary data. Dietary information was obtained by trained interviewers who visited each participating household and solicited one 24-h recall from each participant in the survey during each round. The means of the two independent 24-h recalls were used for these analyses to stabilize seasonal differences. Food models were used to aid participants in estimating intake amounts in order to help improve quality of the data. We expect estimates of population intakes to be reasonably accurate.

Data were coded by eating occasion for each person, with each observation representing one food item. Because of the different number of foods eaten per meal per person, the number of observations in the dataset varied for each individual in the study population. This data format was chosen to allow for meal-specific calculations and adjustments for enhancers and inhibitors. A representation of the data structure is provided in Appendix A-1.

Prior to nutrient conversion, the reported dietary intake data were examined for excessive total food intakes, food consumption with zero grams of intake recorded, and extreme intakes of individual foods. Excessive food intakes were either corrected in the file or replaced with median amounts depending on the source of the problem. Intakes of zero grams for any food reportedly consumed were interpreted as being indeterminate and were replaced with the median amount for the food. Finally, to address extreme intakes, the distribution of portion sizes of each food consumed was examined, and any portion size five times greater than the median portion size was replaced with the median amount. This was necessary for 0.5% of the total number of observations.

Assessment of iron intake. Iron values from a Russian food composition table were applied to each subject's 24-h recall to obtain daily total iron intakes per individual. Iron obtained from dietary supplements was not included in our analyses. The food composition table used in our analyses was a revised version of a 642-item nutrient database designed by the Russian Institute of Preventive Medicine (Slirolijom and Shaternikova 1984); a representation of the data structure of the nutrient database is given in Appendix A-2. Three types of modifications were made in revising the table. First, values were modified if they were highly implausible or inconsistent with common knowledge. Here, iron values from the Russian table were compared with values from a separate table developed by the Russian Institute of Nutrition (Skurichin and Volgarev 1987); any iron values over 25% different from those in the Russian Institute of Nutrition table were changed using a standard algorithm to be more consistent with values in other tables, namely, values used in the USDA (1993) and the Bundeslebensmittelschlüssel or the German Federal Food Code tables (Haussler et al. 1991). Finally, values were added for six types of baby formula that were mixing information on nutrient content.

Adjustment for iron bioavailability. Because interactions occur in the gut at the time of food ingestion, the analysis of iron bioavail-
stores. In this case, heme iron availability was assumed to be 25%. Nonheme iron availability was determined based on categories of meal-level MFP and vitamin C intakes shown in Table 1.

Further adjustments to available nonheme iron were made based on the amounts of tea and phytates consumed in the meal. Nonheme iron availability was reduced by 40% when the amount of tea consumed in the same meal exceeded 225 g (Singer et al. 1982). Phytate values were taken primarily from Harland and Oberleas (1987) and were supplemented with other values from Pennington and Church (1985). A variety of methods was used to determine phytate content of foods; these are described in greater detail by Harland and Oberleas (1987). Phytate values were then incorporated into a recipe file containing quantitative information on phytate-containing foods (see Appendix A-4). Approximate values and adjustments were used when Russian foods could not be closely matched with food items in the literature. For mixed dishes, phytate-containing ingredients were identified based on official government recipes in order to estimate the amount of phytate in the entire mixed dish. The amount of available nonheme iron was adjusted for phytates consumed in the meal using the following formula:

\[
\log_{10}(\% \text{ nonheme availability})
= -0.2869 \times \log_{10}(\text{mg phytates in meal}) + 0.1295.
\]

(See Appendix B.) The formula was derived by fitting data from Hallberg et al. (1989) into a logarithmic regression model to estimate parameters. The phytate-phosphorous upon which the Hallberg et al. (1989) model was based was translated into phytate by assuming that phytate-phosphorous constitutes 28% of the hexaphosphate inositol molecule. Although the number of phosphate binding sites on the phytate molecule varies, hexaphosphate seems to be the dominant form (Hallberg et al. 1989). We therefore assume that both the phytate content tables and the absorption model from Hallberg et al. are based on the hexaphosphate inositol molecule.

Statistical analyses. Stratified and multivariate analyses were used to assess the association between iron intakes and rural and

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**TABLE 1**

Assumed percent absorption of nonheme iron based on meal-level intakes of meat, fish and poultry and vitamin C^1^  

<table>
<thead>
<tr>
<th>Vitamin C in meal, mg</th>
<th>Meat, fish, or poultry in mean, g</th>
<th>&lt;25</th>
<th>25–75</th>
<th>&gt;75</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>&lt;25</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>25–75</td>
<td>10</td>
<td>20</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>&gt;75</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

^1^Based on figures from FAO/WHO (1988).

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**TABLE 2**

Daily intakes of Russian women and children, 1992–1993^1^  

<table>
<thead>
<tr>
<th>Group and age, y</th>
<th>Required levels^2^</th>
<th>Energy</th>
<th>Mean intake (25%, 75%)</th>
<th>Fat mean intake</th>
<th>Protein mean intake</th>
<th>Vitamin C</th>
<th>Mean intake (25%, 75%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kJ</td>
<td>g</td>
<td>g</td>
<td>g</td>
<td>levels^2^</td>
<td>mg</td>
</tr>
<tr>
<td>Girls age, y</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–6</td>
<td>2720–5439</td>
<td>5715</td>
<td>56.4</td>
<td>53.8</td>
<td>70</td>
<td>36.8</td>
<td>(21.9, 46.2)</td>
</tr>
<tr>
<td></td>
<td>(4376, 6816)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7–13</td>
<td>8368–9205</td>
<td>6845</td>
<td>67.8</td>
<td>63.1</td>
<td>70</td>
<td>48.4</td>
<td>(25.6, 63.0)</td>
</tr>
<tr>
<td></td>
<td>(5452, 8050)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys age, y</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–6</td>
<td>2720–5439</td>
<td>5887</td>
<td>55.1</td>
<td>54.4</td>
<td>70</td>
<td>37.1</td>
<td>(19.4, 47.4)</td>
</tr>
<tr>
<td></td>
<td>(4686, 6904)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7–13</td>
<td>8368–10,460</td>
<td>7272</td>
<td>71.7</td>
<td>67.3</td>
<td>70</td>
<td>49.6</td>
<td>(26.7, 65.9)</td>
</tr>
<tr>
<td></td>
<td>(5494, 8594)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Women age, y</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14–54</td>
<td>8786–9205</td>
<td>7163</td>
<td>76.4</td>
<td>69.5</td>
<td>70–80</td>
<td>52.3</td>
<td>(29.1, 69.0)</td>
</tr>
<tr>
<td></td>
<td>(5456, 8523)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55–65</td>
<td>8263–8786</td>
<td>6665</td>
<td>67.2</td>
<td>63.6</td>
<td>80</td>
<td>49.9</td>
<td>(26.5, 65.6)</td>
</tr>
<tr>
<td></td>
<td>(4992, 7920)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;65</td>
<td>7113–8263</td>
<td>6033</td>
<td>56.1</td>
<td>55.6</td>
<td>80</td>
<td>48.8</td>
<td>(25.3, 58.4)</td>
</tr>
<tr>
<td></td>
<td>(4586, 7159)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

^1^Intake data represent mean intakes from rounds 1 and 2 of the Russian Longitudinal Monitoring Survey (g = 9890), weighted to represent intakes for the larger population.  

^2^Required and recommended intakes for women are drawn from Russian recommendations.  

For women 55–65 y old, recommendations are based on those for women 18–59/60–74. Recommended intakes of vitamin C are increased by 20 mg for pregnant women and by 40 mg for lactating women. Required and recommended intakes for children are drawn from United States Recommended Daily Allowances (NRC 1989).
ADJUSTMENT FOR IRON AVAILABILITY

FIGURE 2  Mean total iron intakes of American and Russian women and children. Estimates of intake for American women and children are drawn from the third National Health and Nutrition Examination Survey (Alaimo et al. 1994).

urban living status in Russian women and children. Linear regression models were used to assess whether there were statistically significant (P < 0.05) associations between intakes of total, heme and estimated bioavailable iron and rural and urban geography after controlling for the other variables in the model, SAS was used for all analyses.

RESULTS

The diet in general. Mean intakes of macronutrients and selected micronutrients for various age groups of the population are shown in Table 2. The young women consumed an average of 7163 kj/d as a 40% fat diet. Vitamin C intakes were not low, at approximately 50 mg/d. The women and children had high protein diets (53 g/d in young children and 63–70 g/d in older children and adult women). Protein intakes were lower among the elderly women (55 g/d). Intakes of meat, fish and poultry combined were 105 g/d in the adult women. Their tea consumption was 400 mL/d.

Total daily intakes of iron. The mean total amount of iron consumed by women 14–54 y old in this population was 12.5 mg, or 69% of the Russian recommended intake of 18 mg/d (Ministry of Health Protection 1991) and 83% of the United States recommended intake of 15 mg/d (National Research Council 1989). These levels are comparable to those of women in the United States (Alaimo et al. 1994). However, total iron intakes of children were considerably lower than those of United States children (see Fig. 2).

Bioavailable iron intakes. The percentages of total iron intakes that were bioavailable are shown in Table 3. The mean amount of available iron was 8–11% of the total iron intake after adjusting for the absorption enhancers, MFP and vitamin C consumed in the same meal. This is close to the 10% bioavailability assumed by the National Research Council (1989) in setting United States recommendations. Adjusting for tea and phytates in addition to MFP and vitamin C further reduced the percentage of bioavailable iron to 3–4% of total dietary intake.

Figure 3 shows the estimated iron availability in the study population relative to the physiologic range of daily iron needs without addition of the safety margin inherent in a recommended daily allowance. The entire range of intakes in most cases was lower than the lowest portion of the range of physiologic requirements.

TABLE 3

Proportion of total dietary iron available after adjustment for concurrently consumed enhancers and inhibitors

<table>
<thead>
<tr>
<th>Group and age, y</th>
<th>Percent bioavailable I</th>
<th>Percent bioavailable II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girls 0–6</td>
<td>10.8</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>10.1</td>
<td>4.0</td>
</tr>
<tr>
<td>Boys 0–6</td>
<td>10.6</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>9.6</td>
<td>4.0</td>
</tr>
<tr>
<td>Women 14–54</td>
<td>9.5</td>
<td>4.1</td>
</tr>
<tr>
<td>55–65</td>
<td>8.4</td>
<td>3.6</td>
</tr>
<tr>
<td>&gt;65</td>
<td>8.3</td>
<td>3.3</td>
</tr>
</tbody>
</table>

1For present bioavailable I, absorption is adjusted for concurrent consumption of enhancers, heme and vitamin C. For percent bioavailable II, absorption is adjusted for concurrent consumption of both enhancers (heme and vitamin C) and inhibitors (phytates and tea).
more total iron than those in urban areas ($P < 0.01$ in multivariate models for all age groups). Total iron intakes among rural women were 12% (among women 55–65 y old) to 14% (women 14–54 y old) higher than those of urban residents. This is partly due to greater heme iron (meat) intakes among rural women. However, once adjusted for vitamin C intakes, the picture is reversed. Possibly due to higher availability of foods rich in vitamin C in urban areas, enhancer-adjusted bioavailable iron is equal to or significantly greater in the city dwellers. Among women under 65 y of age, adjustment for inhibitors in the diet in addition to enhancers again reverses the trend, with mean intakes of bioavailable iron significantly higher in rural than in urban areas. This indicates that tea and/or high phytate intakes in the cities overwhelm the vitamin C advantage. Among women over 65 y of age, the bioavailable iron levels after all adjustments are equally low in both city and countryside, with daily intakes only 60–70% of those of younger women. It is interesting to note that residence in urban vs. rural areas was not a significant predictor of dietary iron intakes among children.

**DISCUSSION**

This work serves both to introduce a method of adjustment for iron availability in population studies and to examine its use in a population vulnerable to inhibition of iron absorption. The adjustments made are based upon the physiologic findings from experimental studies of bioavailability.

Few nutritional epidemiology studies capture the information required for assessment of iron bioavailability—namely, data on dietary intake for each eating occasion and recipe files containing quantitative information for mixed dishes. The importance of this information is evidenced by our analyses showing that only a small proportion of total iron intake was bioavailable for this population of Russian women after adjustment for other factors consumed in the same meal. Estimates of mean percent bioavailability assuming adequate iron stores ranged from 8–11%, when adjusted for MFP and vitamin C, to as low as 3.3–4% following further adjustment for phytates and black tea consumption. Such bioavailability estimates have important implications if they are lower than the proportions of bioavailability assumed when setting recommendations; low bioavailability is especially of concern in developing countries, where diets may contain high levels of inhibitors of iron absorption.

Our research also indicates that iron intakes in this population were lower than both the recommended and the required levels of intake for Russian women of reproductive age, although the extent of inadequacy in the population is not readily estimable from these analyses alone. Total iron intake was 69% of the recommended amount of 18 mg/d for Russian women. Furthermore, after adjustment for both enhancers and inhibitors of iron absorption, the mean and 25th to 75th percentiles of mean percent bioavailability for this population of Russian women after adjustment for enhancers and inhibitors of iron absorption show that only a small proportion of total iron intake was bioavailable.

**FIGURE 3** Mean levels and 25th to 75th percentile ranges of bioavailable iron adjusted for inhibitors (phytates and tea), relative to estimated iron requirements. Shaded bars represent range of estimated iron requirements for growth and maintenance.

**TABLE 4**

<table>
<thead>
<tr>
<th>Group and age, y</th>
<th>Urban2</th>
<th>Rural</th>
<th>$P^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Girls</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–6, n</td>
<td>(290)</td>
<td>(96)</td>
<td>0.68</td>
</tr>
<tr>
<td>Total iron</td>
<td>8.51</td>
<td>8.07</td>
<td></td>
</tr>
<tr>
<td>Heme</td>
<td>0.85</td>
<td>0.72</td>
<td>0.45</td>
</tr>
<tr>
<td>Bioavail. I</td>
<td>0.93</td>
<td>0.84</td>
<td>0.43</td>
</tr>
<tr>
<td>Bioavail. II</td>
<td>0.35</td>
<td>0.31</td>
<td>0.28</td>
</tr>
<tr>
<td>7–13, n</td>
<td>(377)</td>
<td>(116)</td>
<td>0.18</td>
</tr>
<tr>
<td>Total iron</td>
<td>11.13</td>
<td>10.99</td>
<td></td>
</tr>
<tr>
<td>Heme</td>
<td>1.14</td>
<td>1.11</td>
<td>0.74</td>
</tr>
<tr>
<td>Bioavail. I</td>
<td>1.14</td>
<td>1.05</td>
<td>0.33</td>
</tr>
<tr>
<td>Bioavail. II</td>
<td>0.35</td>
<td>0.36</td>
<td>0.79</td>
</tr>
<tr>
<td><strong>Boys</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–6, n</td>
<td>(277)</td>
<td>(83)</td>
<td></td>
</tr>
<tr>
<td>Total iron</td>
<td>8.52</td>
<td>9.08</td>
<td>0.41</td>
</tr>
<tr>
<td>Heme</td>
<td>0.83</td>
<td>0.87</td>
<td>0.65</td>
</tr>
<tr>
<td>Bioavail. I</td>
<td>0.90</td>
<td>0.95</td>
<td>0.90</td>
</tr>
<tr>
<td>Bioavail. II</td>
<td>0.35</td>
<td>0.36</td>
<td>0.79</td>
</tr>
<tr>
<td>7–13, n</td>
<td>(414)</td>
<td>(103)</td>
<td>0.18</td>
</tr>
<tr>
<td>Total iron</td>
<td>11.77</td>
<td>12.24</td>
<td></td>
</tr>
<tr>
<td>Heme</td>
<td>1.24</td>
<td>1.22</td>
<td>0.94</td>
</tr>
<tr>
<td>Bioavail. I</td>
<td>1.15</td>
<td>1.11</td>
<td>0.69</td>
</tr>
<tr>
<td>Bioavail. II</td>
<td>0.49</td>
<td>0.49</td>
<td>0.87</td>
</tr>
<tr>
<td><strong>Women</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14–54, n</td>
<td>(2633)</td>
<td>(555)</td>
<td></td>
</tr>
<tr>
<td>Total iron</td>
<td>12.29</td>
<td>14.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Heme</td>
<td>1.31</td>
<td>1.49</td>
<td>0.00</td>
</tr>
<tr>
<td>Bioavail. I</td>
<td>1.20</td>
<td>1.16</td>
<td>0.22</td>
</tr>
<tr>
<td>Bioavail. II</td>
<td>0.51</td>
<td>0.57</td>
<td>0.00</td>
</tr>
<tr>
<td>55–65, n</td>
<td>(581)</td>
<td>(233)</td>
<td></td>
</tr>
<tr>
<td>Total iron</td>
<td>11.57</td>
<td>13.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Heme</td>
<td>1.01</td>
<td>1.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Bioavail. I</td>
<td>1.02</td>
<td>0.98</td>
<td>0.23</td>
</tr>
<tr>
<td>Bioavail. II</td>
<td>0.42</td>
<td>0.45</td>
<td>0.02</td>
</tr>
<tr>
<td>65+, n</td>
<td>(644)</td>
<td>(265)</td>
<td></td>
</tr>
<tr>
<td>Total iron</td>
<td>10.54</td>
<td>11.80</td>
<td>0.01</td>
</tr>
<tr>
<td>Heme</td>
<td>0.85</td>
<td>0.74</td>
<td>0.06</td>
</tr>
<tr>
<td>Bioavail. I</td>
<td>0.92</td>
<td>0.87</td>
<td>0.02</td>
</tr>
<tr>
<td>Bioavail. II</td>
<td>0.37</td>
<td>0.33</td>
<td>0.16</td>
</tr>
</tbody>
</table>

$^1$Intakes are mean from rounds 1 and 2 of the Russian Longitudinal Monitoring Survey, weighted to represent intakes for the larger population.

$^2$Classification by urban/rural residence was based on data from round 1.

$^3$P value for association of urban/rural residence with dietary iron intake, calculated from multivariate linear regression modeling controlling for education level, number of children in household, poverty level, smoking status, body mass index, and mean alcohol intake.
centile range of estimated available iron tended to be less than even the lower end of the range of physiological iron requirements. This suggests that the level of iron inadequacy in this population may be considerably lower than what would be surmised based on total iron intakes alone.

Three previous studies adjusting for iron availability while assessing iron intakes have been based on Monsen’s meal-based algorithms adjusting for MFP and vitamin C (Monsen and Balintfy 1982, Monsen et al. 1978). Raper et al. (1984), using data from USDA 1977–1978 Nationwide Food Consumption Survey, found that total iron intakes for women from 15 to 50 y old ranged from 55 to 59% of the Recommended Dietary Allowance. Adjustment for MFP and vitamin C, estimates were slightly lower; available iron ranged only from 45 to 48% of required amounts, and percent bioavailability averaged around 8%, less than the 10% assumed in setting the recommendations. Similarly, Vigglietti and Skinner (1987), using data from food records of 224 adolescents, showed slightly less adequate levels of intake based on available iron than on total iron intakes; whereas iron intakes were 89 and 62% of the RDA for adolescent boys and girls, respectively, available iron after adjusting for MFP and vitamin C was 77% of the required amount for adolescent boys and only 51% that for adolescent girls. Again, percent bioavailability—between 8 and 9% for adolescent boys and girls—was less than the 10% assumed in setting the RDA. In another study, conducted in rural Mexico, Black et al. (1994) found total iron intakes that were two to three times the RDA for adult men and women. After adjustment for MFP and vitamin C, available iron was 120% of the RDA for men but 87% of the RDA for women; however, because of the high intakes of fiber and phytate in their population, the authors note that these are probably overestimates.

The studies by Raper et al. (1984) and Vigglietti and Skinner (1987) found lower levels of total and available iron for women relative to recommended amounts than did our study. In these studies, total iron intakes were 55–62% of recommended amounts compared with 69% of the Russian recommendation in our study, whereas available iron after adjustment for MFP and vitamin C was 45–51% of required levels compared with about 76% in our study; percent bioavailability after adjustment for MFP and vitamin C was also slightly less favorable in these studies (8–9% compared with our finding of 9.5%). However, the results of the two studies, as well as the study by Black et al. (1994), are consistent with the finding that less favorable pictures of dietary iron adequacy are obtained after adjusting for bioavailability than from looking only at total iron intakes. In our study, iron intake expressed as a percentage of recommendation was actually lower than bioavailable iron adjusted for MFP and vitamin C expressed as a percentage of iron requirements; this is most likely attributable to the higher recommended intake of iron for women in Russia than in the United States.

Few previous studies have adjusted for factors other than MFP and vitamin C. In a study by Singer et al. (1982), iron intakes were categorized as having low, medium or high availability based on the presence of MFP and vitamin C in the same meal, according to an algorithm similar to that described by Monsen et al. (1978). Iron availability was further adjusted for tea by reducing iron intake by one category of bioavailability. Percent availability of heme and nonheme iron was then calculated based on the category in which it fell. In this study, further adjusting for tea did not seem to change mean levels of available iron substantially from mean levels obtained after adjusting for MFP and vitamin C alone.

In a study on toddlers in Egypt, Kenya and Mexico, Murphy et al. (1992) also adjusted for MFP and vitamin C using an algorithm based on Monsen’s method (Monsen et al. 1978), with three major differences: 1) the MFP and vitamin C cutoff values used to categorize intakes as having low, medium or high availability were transformed into nutrient densities and applied to toddlers; 2) because meal-level information was not available, the algorithm was applied to daily intakes; and 3) the percent availability of nonheme iron for each category was changed to the levels suggested by FAO/WHO (1988), ranging from 5 to 15% as in our sensitivity analysis. To further adjust for tea, nonheme iron was then multiplied by a “tea factor” ranging from 1.00 to 0.40 depending on the amount of tea consumed. The authors found that estimated iron availability ranged from 5.5% in Mexico to 8.7% in Kenya, as compared with 7.7% in our study after adjustment for tea in addition to MFP and vitamin C. The reduction of nonheme iron availability due to tea ranged from 6 to 16%.

No previous studies have adjusted iron availability for the effects of phytates. One study by Cook et al. (1991) considered a large variety of enhancers and inhibitors—specifically, MFP, vitamin C, tea, coffee, whole wheat bread, bran muffin or bran cereal and eggs. However, these factors were not used to determine the amounts of iron available from total iron intake. Rather, they were used to create meal scores to rank nonheme iron bioavailability, with larger scores representing meals with higher nonheme iron availability. Nevertheless, Cook et al. (1991) found that the meal scores correlated well with actual absorption, suggesting that these dietary factors are useful for ranking the quality of individual meals for iron bioavailability.

Several factors limited our ability to accurately estimate iron bioavailability in this study. Although the interactions of enhancers and inhibitors of iron absorption are complex (Hallberg et al. 1989, Siegenberg et al. 1991), our adjustments for the presence of MFP, vitamin C, tea and phytates were based on algorithms created from interpretations of the results of experimental work, primarily human feeding studies. Moreover, our algorithms assumed only additive effects and did not attempt to quantify interactions among dietary factors; currently, no model exists to estimate the effects of enhancers and inhibitors acting simultaneously on iron absorption. In addition, iron availability may be affected by still other factors not included in our analyses, such as coffee (Morck et al. 1983), calcium (Hallberg et al. 1991) or the proportion of iron derived from fortification (Hallberg and Rossander-Hulten 1991). Estimates of iron availability would be improved by further investigation into the effects and interactions of other dietary factors affecting iron absorption.

Our analyses were also limited by lack of information on iron status, another major determinant of iron absorption. The algorithms used to adjust for iron availability were appropriate for a reference individual with well-supplied iron reserves; thus, the maximum level of nonheme iron bioavailability allowed by our algorithms was 8%. We believed this to be a reasonable assumption, because high intakes of red meat prior to economic reforms probably contributed significantly to long-term iron stores in this population. If iron status was less adequate than what we assumed, however, the actual level of iron bioavailability may be higher. Indeed, in a sensitivity analysis allowing a maximum level of nonheme iron bioavailability of 15%, mean available iron was considerably greater than estimates based on adequate iron stores. It is notable, nevertheless, that while mean available iron adjusting for MFP and vitamin C seemed to meet the estimated requirements for the population, it was still under half of the estimated requirement when further adjustment was made for phytates; thus, our conclusion that adjustment for enhancers and inhibitors of iron absorption should be considered in assessing bioavailability is not changed. However, future research in this area would benefit from the use of biochemical indicators both
to help improve estimates of iron availability and to validate the extent of iron insufficiency in populations.

Despite these limitations, the ability to adjust for iron bioavailability is potentially useful in several respects. Because quality of the diet varies greatly across populations, an awareness of the proportion of total iron that is bioavailable in different settings would help inform decisions on recommended levels of intake and on patterns of food intake. Research in this area could identify the major as well as underutilized food sources of bioavailable iron in populations. These findings are important in nutrition education efforts—especially in areas with less varied diets where, because of the likely imbalance between enhancers and inhibitors of iron absorption, bioavailability more strongly determines iron status (Cook et al. 1991). In this case, altered patterns of tea consumption, enhanced intakes of sources of ascorbate at meals, and knowledge of phytate-rich foods could improve iron status significantly. Better understanding of adjustment for iron bioavailability also has important implications for policy recommendations. For example, under dietary conditions such as in Russia, where tea is consumed with every meal and phytate intakes are high, fortification of the food supply with iron will do less to improve iron nutriture than educational attempts at changing the meal pattern. In this case, again, educational measures may include encouraging the substitution of black tea with herbal teas or drinking tea at times other than during the nonheme-rich meals.

Our analyses suggest that only a small proportion of total iron intake is bioavailable after other factors in the meal, especially phytates, are considered. In addition, adjusting for other dietary factors may offer a less optimistic picture of the adequacy of dietary iron in a population compared with estimates based on total iron intake. In specific instances, such as comparisons of adequacy in rural and urban areas, the profile of concurrently consumed enhancers and especially inhibitors can profoundly affect conclusions.

Given the potential usefulness of adjusting for iron bioavailability, future research on the adequacy of dietary iron in populations should include some component to estimate available iron as well. Such research would necessarily involve collection of dietary data at the meal level. Because amounts of enhancers and inhibitors most likely vary across meals, information on daily intakes would not capture the effects of these dietary factors on iron availability; meal-level information may more accurately indicate the degree of adequacy or inadequacy of iron intakes in a population than would information on daily intakes. In addition, estimation of iron availability would also require detailed information on food composition, including recipe files for mixed dishes, as well as information on dietary factors not normally included in nutrient databases, such as phytates. The health consequences of iron inadequacy are well known. More recently, iron excess has drawn greater attention as well. Because the estimation of iron availability could potentially offer a more accurate measure of the actual amount of iron received from the diet, adjustment for bioavailability is worth pursuing in future studies on iron intake.

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LITERATURE CITED


APPENDIX A
Databases and Data Structures Needed for Iron Bioavailability Adjustments

A-1. Dietary data (DIET)

Dietary information was stored with each observation representing one food item consumed per meal per person as shown below. Each FOODCODE could be listed more than once for each person if consumed at different eating occasions. Number of observations per person varied depending on number of food items consumed by the person.

<table>
<thead>
<tr>
<th>PERSON1</th>
<th>MEAL2</th>
<th>FOODCODE3</th>
<th>FOODNAME</th>
<th>GRAMS4</th>
</tr>
</thead>
<tbody>
<tr>
<td>602</td>
<td>1</td>
<td>531</td>
<td>sugar</td>
<td>5.0</td>
</tr>
<tr>
<td>602</td>
<td>1</td>
<td>582</td>
<td>instant coffee</td>
<td>200.0</td>
</tr>
<tr>
<td>602</td>
<td>1</td>
<td>74</td>
<td>butter</td>
<td>5.0</td>
</tr>
<tr>
<td>602</td>
<td>3</td>
<td>404</td>
<td>wheat bread</td>
<td>25.0</td>
</tr>
<tr>
<td>602</td>
<td>3</td>
<td>58</td>
<td>tea</td>
<td>200.0</td>
</tr>
<tr>
<td>602</td>
<td>5</td>
<td>231</td>
<td>frankfurter</td>
<td>112.0</td>
</tr>
<tr>
<td>602</td>
<td>5</td>
<td>376</td>
<td>mashed potato</td>
<td>100.0</td>
</tr>
<tr>
<td>602</td>
<td>5</td>
<td>585</td>
<td>tea</td>
<td>200.0</td>
</tr>
<tr>
<td>5102</td>
<td>1</td>
<td>585</td>
<td>tea</td>
<td>200.0</td>
</tr>
<tr>
<td>5102</td>
<td>3</td>
<td>97</td>
<td>margarine</td>
<td>8.0</td>
</tr>
<tr>
<td>2070802</td>
<td>5</td>
<td>585</td>
<td>tea</td>
<td>200.0</td>
</tr>
<tr>
<td>2070802</td>
<td>6</td>
<td>404</td>
<td>wheat bread</td>
<td>25.0</td>
</tr>
<tr>
<td>2070802</td>
<td>6</td>
<td>585</td>
<td>tea</td>
<td>200.0</td>
</tr>
</tbody>
</table>

1Unique identifier for each subject.
2Code for each meal or eating occasion.
3Unique identifier to match each food item in food composition table (FCT).
4Grams of food consumed.

A-2. Food composition table (FCT)

Nutrient composition data was organized with each observation representing one food item. The data shown below include information incorporated from mixed dish recipe file (MIXED).

<table>
<thead>
<tr>
<th>FOODCODE1</th>
<th>FOODNAME</th>
<th>MEATCODE2</th>
<th>MEAT_FCT3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>milk, 6% fat</td>
<td>0.100</td>
<td>1.300</td>
</tr>
<tr>
<td>2</td>
<td>milk, 3% fat</td>
<td>0.080</td>
<td>1.300</td>
</tr>
<tr>
<td>3</td>
<td>milk, 1.5% fat</td>
<td>0.080</td>
<td>1.300</td>
</tr>
<tr>
<td>4</td>
<td>protein milk</td>
<td>0.100</td>
<td>0.400</td>
</tr>
<tr>
<td>5</td>
<td>raw milk</td>
<td>0.080</td>
<td>1.300</td>
</tr>
<tr>
<td>640</td>
<td>fruit sauce and cream</td>
<td>1.300</td>
<td>0.00</td>
</tr>
<tr>
<td>641</td>
<td>beef sauce</td>
<td>1.300</td>
<td>0.00</td>
</tr>
<tr>
<td>642</td>
<td>meat sauce, &quot;petushock&quot;</td>
<td>1.300</td>
<td>0.00</td>
</tr>
</tbody>
</table>

1Unique identifier for each food item.
2mg iron per 100 g food item.
3mg vitamin C per 100 g food item.
4Proportion of the food by weight that is meat.
5mg phytate per 100 g phytate-containing food. Amount of phytate (mg) per mixed dish can then be calculated as PHYPROP x mg mixed dish x PHYTATE/100. For example, 22.6% of 50 g beef cutlet contains 0.226 x 50 g x 183 mg phytate/100 g = 20.7 mg phytate.
6Type of food, where 1 represents all-meat foods, 2 represents mixed dishes, and 3 represents non-meat foods.

A-3. Recipe file for mixed dishes with meats (MIXED)

Data on meat content of mixed dishes was organized with each observation representing one meat per mixed dish as shown below. A mixed dish could include more than one type of meat. Information from the recipe file on meat content can be incorporated into the food composition table (FCT) and used to calculate heme and nonheme iron content of mixed dishes.

<table>
<thead>
<tr>
<th>FOODCODE1</th>
<th>FOODNAME</th>
<th>MEATCODE2</th>
<th>MEAT_FCT3</th>
</tr>
</thead>
<tbody>
<tr>
<td>129</td>
<td>beef stroganoff</td>
<td>107 (beef)</td>
<td>0.50</td>
</tr>
<tr>
<td>131</td>
<td>goulash, beef</td>
<td>107 (beef)</td>
<td>0.40</td>
</tr>
<tr>
<td>32</td>
<td>goulash, pork</td>
<td>111 (pork)</td>
<td>0.40</td>
</tr>
<tr>
<td>135</td>
<td>ragout, mutton</td>
<td>106 (mutton)</td>
<td>0.20</td>
</tr>
<tr>
<td>136</td>
<td>ragout, pork</td>
<td>111 (pork)</td>
<td>0.20</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>561</td>
<td>meat stuffing</td>
<td>107 (beef)</td>
<td>0.80</td>
</tr>
<tr>
<td>641</td>
<td>beef sauce</td>
<td>107 (beef)</td>
<td>0.80</td>
</tr>
<tr>
<td>642</td>
<td>meat sauce, &quot;petushock&quot;</td>
<td>107 (beef)</td>
<td>0.80</td>
</tr>
</tbody>
</table>

1Unique identifier for each mixed dish to match food items in food composition table (FCT).
2Unique identifier to match meat items in food composition table (FCT).
3Proportion of the mixed dish by weight that is meat.

A-4. Recipe file for mixed dishes with phytates (PHYTATES)

Data on phytate content of mixed dishes was organized with each observation representing one phytate-containing food per mixed dish as shown below.

<table>
<thead>
<tr>
<th>FOODCODE1</th>
<th>FOODNAME</th>
<th>PHYFOOD2</th>
<th>PHYPROP3</th>
<th>PHYTATE4</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>coffee with condensed milk</td>
<td>581 (coffee)</td>
<td>0.04</td>
<td>368</td>
</tr>
<tr>
<td>26</td>
<td>coffee with condensed cream</td>
<td>581 (coffee)</td>
<td>0.04</td>
<td>368</td>
</tr>
<tr>
<td>145</td>
<td>beef patties</td>
<td>404 (wheat bread)</td>
<td>0.085</td>
<td>183</td>
</tr>
<tr>
<td>149</td>
<td>meatloaf, egg-filled</td>
<td>404 (wheat bread)</td>
<td>0.093</td>
<td>183</td>
</tr>
<tr>
<td>151</td>
<td>beef cutlets</td>
<td>404 (wheat bread)</td>
<td>0.226</td>
<td>183</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>563</td>
<td>rice/egg stuffing</td>
<td>997 (rice)</td>
<td>0.30</td>
<td>140</td>
</tr>
<tr>
<td>581</td>
<td>coffee</td>
<td>581 (coffee)</td>
<td>1.00</td>
<td>2</td>
</tr>
<tr>
<td>584</td>
<td>coffee with milk</td>
<td>581 (coffee)</td>
<td>0.04</td>
<td>368</td>
</tr>
</tbody>
</table>

1Unique identifier for each mixed dish to match food items in food composition table (FCT).
2Unique identifier for each phytate-containing food.
3Proportion of the mixed dish by weight that is a phytate-containing food.
4mg phytate per 100 g phytate-containing food. Amount of phytate (mg) per mixed dish can then be calculated as PHYPROP x g mixed dish x PHYTATE/100. For example, 22.6% of beef cutlets is wheat bread, whose phytate content is 183 mg phytate per 100 g wheat bread; thus, 50 g beef cutlet contains 0.226 x 50 g x 183 mg phytate/100 g = 20.7 mg phytate.
APPENDIX B
Sample SAS Programs for Iron Adjustments

******************************************************************************
** PROGRAM FOR:                      **
**  (1) PREPARING FOOD COMPOSITION TABLE FOR ADJUSTMENT FOR MFP/VIT C **
**  (2) CALCULATING HEME AND NON-HEME IRON, VIT C, **
**  AND MEAL CONSUMPTION FROM DIETARY INTAKE DATA **
**  (3) ADJUSTING FOR MEAL-LEVEL VIT C/MFP **
******************************************************************************

;******************************************************************************
** INPUT DATASETS:                     **
**  1. DIET: DIETARY INTAKE DATA, INDIVIDUAL FOOD-LEVEL  **
**  2. FCT: FOOD COMPOSITION TABLE DATA  **
** OUTPUT DATASETS:                     **
**  1. MEAL: DIETARY INTAKE DATA, MEAL-LEVEL,  **
**      WITH VIT C/MFP ADJUSTED IRON CONTENT  **
**  2. BIODIET: DIETARY INTAKE DATA, INDIVIDUAL FOOD-LEVEL,  **
**      WITH VIT C/MFP ADJUSTED IRON CONTENT  **
******************************************************************************

libname in1 'Path name for dietary intake dataset (DIET)';
libname in2 'Path name for food composition table dataset (FCT)';
libname out1 'Path name for dietary intake datasets (MEAL, BIODIET)
    following adjustments for vitamin C and MFP';

******************************************************************************
* This section adds 2 variables to food composition table dataset FCT.  *
* Two variables are:  *
* (1) HEME_FCT: mg heme iron per 100 g food  *
* (2) NHEM_FCT: mg non-heme iron per 100 g food  *
* The variables are calculated according to whether food is  *
* type 1 (all meat), type 2 (mixed dish), or type 3 (non-meat)  *
* New food composition table is dataset FCT2.  *
******************************************************************************

proc sort data=in2.fct out=fcsort; by foodcode; run;
data fct2;
  set fcsort;
  by foodcode;

  ******************************************************************************
  * ALL-MEAT DISHES:       *
  * Heme is 40% of total iron in meat.  *
  * Non-heme is 60% of total iron in meat.*  *
  ******************************************************************************
  if type=1 then do;
    heme_fct = fe_fct * 0.40;
    nhemefct = fe_fct * 0.60;
  end;

  ******************************************************************************
  * MIXED DISHES:        *
  * Heme is 40% of iron in meat portion of mixed dish.  *
  * Non-heme is remainder of iron in the dish.  *
  ******************************************************************************
  else if type=2 then do;
    heme_fct = MTFE_FCT * 0.40;
  end;

******************************************************************************
nHEMEFCT = FE_FCT - heme;
if nHEME < 0 then do;
   heme = MTFE_FCT;
   nHEME = 0;
end;
end;

***************************************************************************
* NON-MEAT DISHES:     *
* Amount of heme is 0.  *
* All iron is non-heme. *
***************************************************************************
else if type=3 then do;
   heme_fct = 0;
   nHEMEFCT = FE_FCT;
end;
run;

***************************************************************************
* This section            *
* (1) merges food composition table FCT2 with dietary dataset DIET   *
*     by FOODCODE,     *
* (2) calculates mg vitamin C, mg heme and non-heme iron, and g meat *
*     consumed for each observation.    *
* (3) Resulting dataset has one observation for each food consumed  *
*     at each meal by each person. New dataset is COMBO.            *
***************************************************************************
;
proc sort data=fct2; by foodcode; run;
proc sort data=inl.diet out=dietsort; by foodcode; run;
data combo;
    merge fct2 dietsort; by foodcode;
    meat = meat_fct * grams;        /* MEAT = g meat consumed for each food */
    array nut(3) vitc_fct heme_fct nHEMEFCT; /* from food composition table */
    array consum(3) vitc heme nheme;       /* VITC, HEME, and NHEME = mg consumed for each food */
    do i=1 to 3;
       consum(i) = nut(i) * (grams/100);
    end;
run;

***************************************************************************
* This section            *
* (1) sums mg of HEME, NHEME, and VITC and g of MEAT consumed       *
*     over entire meal - these are variables                       *
* (2) calculates enhancing factor EF based on Monsen algorithm,    *
* (3) calculates percent (PCT) of non-heme iron absorbed           *
*     based on presence of enhancing factors,                      *
* (4) calculates mg bioavailable iron from the meal.              *
***************************************************************************
;
proc sort data=combo; by person meal; run;
data mealtemp;
set combo;
by person meal;
keep person meal m_heme m_nheme m_vitc m_meat;

array consum(4) heme nheme vitc meat;
array m_consum(4) m_heme m_nheme m_vitc m_meat;

/* M_HEME, M_NHHEME, M_VITC, and M_MEAT are mgs heme and non-heme iron and vitamin C and g meat consumed over entire meal for each person */

retain person meal;
do j=1 to 4;
m_consum(j) + sum(0,consum(j));
end;
if last.meal then do;
    output;
do k=1 to 4;
m_consum(k)=0;
end;
end;
run;
data out1.meal;
set mealtemp;
keep person meal pct;

ef = m_meat + m_vitc;
/* EF is enhancing factor based on Monsen algorithm, set to missing if either M_MEAT or M_VITC is missing */
if ef=. then ef=0;
else if ef<75 then pct = 3+(8.93*log((ef+100)/100));
else if ef>=75 then pct = 8; /* PCT is percent of non-heme available adjusting for enhancing factors */

m_nhabs = (pct/100) * m_nheme,
m_habs = 0.23 * m_heme;
m_totabs = m_nhabs + m_habs;
run;
data out1.biodiet;
merge combo meal; by person meal;
bioiron = (0.23*heme) + ((pct/100)*nheme); /* BIOIRON is total bioavailable iron in each food consumed */
run;
** PROGRAM FOR: **
** (1) CALCULATING PHYTATE CONSUMPTION FROM DIETARY INTAKE DATA **
** (2) ADJUSTING FOR MEAL-LEVEL CONSUMPTION OF PHYTATES AND TEA **

;  

** INPUT DATASETS: **
** 1. BIODIET: DIETARY INTAKE DATA, INDIVIDUAL FOOD-LEVEL **
** 2. PHYTATES: PHYTATE RECIPE FILE **
** OUTPUT DATASET: **
** PHYDATA: DIETARY INTAKE DATA, MEAL-LEVEL, WITH IRON INTAKES **
** ADJUSTED FOR VIT C/MFP, PHYTATES, AND TEA **

;  

libname in1 'Path name for dietary intake datasets (BIODIET, MEAL)';
libname in2 'Path name for phytate recipe file (PHYTATES)';
libname out1 'Path name for dietary intake datasets (PHYDATA) following adjustments for phytates and tea';

******************************************************************************
* This section *
* (1) merges food-level dataset BIODIET with phytate dataset PHYTATES *
* by FOODCODE *
* (2) calculates mg phytate in each food consumed. *
** Resulting dataset is similar to original dataset BIODIET — it has one observation for each food consumed at each meal * 
* by each person, but has additional variable PHYTATE. *
* New dataset is PHYDIET. *
******************************************************************************
;

proc sort data=in2.phytates out=physort; by foodcode; run;
proc sort data=in1.biodiet (keep=person meal foodcode grams) out=bdiet_tp;
   by foodcode; run;
data phydiet;
   merge bdiet_tp physort; by foodcode;
   phyrate = (prop*grams)*(phy/100); /* PHYTATE is mg phytate in each food consumed */
   if phyrate=. then phyrate=0;
run;

******************************************************************************
** This section *
** (1) sums mg of PHYTATE and g of TEA consumed over entire meal — *
** these are variables MPHYTE and M_TEA *
** (2) calculates correction factor CT based on phytates in meal *
** (3) calculates percent of non-heme iron absorbed adjusting for *
** (a) phytates, (b) tea, and (c) phytates and tea *
** (4) calculates mgs bioavailable iron from the meal. *
** Resulting dataset PHYDATA has one observation per meal per person *
******************************************************************************;

proc sort data=phydiet; by person meal;
data phymeal;
   set phydiet; by person meal;
   if foodcode = 585 then tea = grams; /* FOODCODE for tea is 585 */
   else tea=0;
   m_tea + tea; /* MPHYTE and M_TEA are mgs phytate and g tea consumed over entire meal for each person */
   mphyte + phyrate;
if last.meal then do;
    output;
    mphytate = 0;
    m_tea = 0;
end;
run;
proc sort data=inv.meal out=mealsort; by person meal; run;
data out1.phydata;
    merge mealsort phythemeal; by person meal;
    /* ADJUSTMENT FOR PHYTATES */
if mphytate <> 0 then ct = 10**(0.2869*log10(mphytate)+0.1295);
    else ct = 1;
    nh_phy = m_nhabs * ct;
    /* CT is correction term for non-heme iron availability based on presence of phytates in meal, using data from Hallberg et al. (1989) */
if m_tea > 225 then nh_tea = 0.6*m_nhabs;
    else if m_tea <=225 Then nh_tea=m_nhabs;
    /* 60% non-heme availability assumed with >225 g tea consumed in meal */
    /* ADJUSTMENT FOR PHYTATES AND TEA */
if m_tea > 225 then nhphytea = 0.6*nh_phy;
    else if m_tea <=225 then nhphytea=nh_phy;
    m_tabs1 = sum(nh_phy,m_habs);
    m_tabs2 = sum(nh_tea,m_habs);
    m_tabs3 = sum(nhphytea,m_habs);
run;